ABANDONED MINE LANDS

BELT - SAND COULEE, MONTANA

WESTECH / HYDROMETRICS

VOLUME IIa

VOLUME II A

INVESTIGATION OF ACID DRAINAGE FROM ABANDONED COAL MINES AND ASSESSMENT OF POTENTIAL METHODS OF IMPACT ABATEMENT

SAND COULEE AND BELT CREEK
CASCADE COUNTY, MONTANA

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February 19, 1982

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SAND COULEE AND BELT CREEK CASCADE COUNTY, MONTANA

The Sand Coulee and Belt Creek drainages located in west central Montana near Great Falls, (Figure 1) contain numerous underground mines which once produced considerable lignite coal for use as railroad fuel and for home heating. These underground mines have long since been abandoned leaving acres of mine wastes, numerous open adits, areas of subsidence, dilapidated mine facilities, and associated mine debris. Many of the abandoned mines generate a highly acidic effluent containing high concentrations of dissolved salts and metals. Mine effluent from the old adits has contaminated streams and destroyed or degraded the aquatic communities in these streams and several acres of farmland have also been ruined by the discharge of acid mine waters. The contaminated streams in the area also have encouraged local residents to dump other wastes into the stream channels causing additional pollution.

The Federal Surface Mining Control and Reclamation Act of 1977 provides federal funds for reclamation of abandoned mine lands through Title IV of the Act. The Montana Department of State Lands (DSL), Reclamation Division, is presently administering an Abandoned Mine Land Reclamation Program which uses federal funds to reclaim abandoned mines in Montana.

Purpose and Scope

A cooperative agreement between the Montana Department of State Lands (DSL) and the Federal Office of Surface Mining (OSM) provides for an investigation of the environmental impacts and consequences of past coal mining in the Sand Coulee and Belt areas and to identify problems resulting from the abandonment of these mines. Results of this

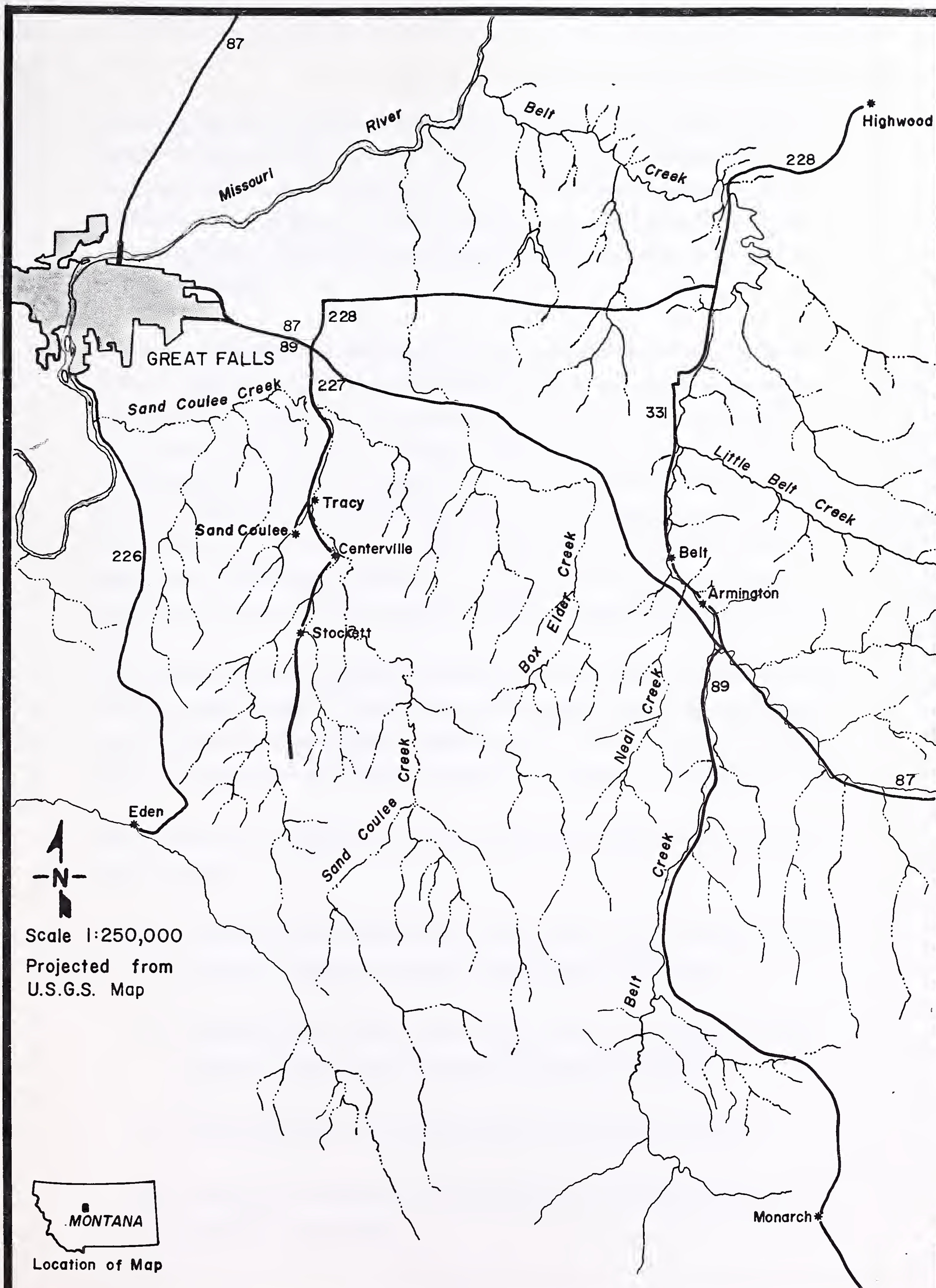


Figure I Location Map of the Sand Coulee & Belt Creek Drainages.

investigation will be coordinated with the results of other environmental studies of the Sand Coulee and Belt Creek drainages to develop a comprehensive master plan for reclamation projects in these areas. Emphasis in this program is on elimination, control or mitigation of existing environmental problems created by the abandoned mines.

Western Technology and Engineering, Inc. and Hydrometrics, both of Helena, Montana, jointly investigated the environmental effects of abandoned coal mines in the Sand Coulee and Belt Creek drainages. This joint investigation included a comprehensive study of the environmental problems in these areas including social-economic impacts, vegetation, soils, air quality and hydrology. Results of this comprehensive study have been integrated into a master plan describing recommended reclamation projects, pollution abatement, disturbed land restoration, monitoring, and recommended future work.

The geology and the hydrology of the Sand Coulee and Belt Creek areas and the significance of both to the causes and effects of the mine discharge were investigated by Hydrometrics. This included evaluation of techniques to eliminate, abate or mitigate acid mine drainage.

Work specifically completed for the geology and hydrology investigation include:

1) Survey of abandoned mines in the Sand Coulee and Belt areas and an inventory of mines discharging acid water.

2) Examination of the areal extent of the acid mine drainage, including the area or stream receiving discharge.

3) Determination of mine discharge quality and quantity.

4) Geological mapping of affected area in the Sand Coulee and Belt drainages.

5) Evaluation of surface water and groundwater hydrology in the affected drainages.

6) Review of acid mine drainage (AMD) control and abatement technology and technical and economic evaluation of abatement techniques for discharging mines.

7) Development of recommendations for further work to more accurately define and correct specific problems of AMD in the study area.

8) Integration with other environmental efforts in the drainages to develop a comprehensive master plan for reclamation.

Previous Investigations

Several investigations have been completed which describe the geology and groundwater resources in the Sand Coulee-Stockett area and several publications discuss the economic geology and coal deposits of the area. Only one investigation of acid mine pollution in the Sand Coulee area has been completed. This investigation was completed by McArthur (1970) as part of a Master's thesis at Montana State University. McArthur discussed causes and effects of acid mine pollution as a result of the discharge from abandoned mines in the Sand Coulee Creek drainage. McArthur located 22 mines that were discharging or showed evidence of discharge during his investigation. He described the extent, concentration and quantity of acid mine drainage from these mines. In addition, he investigated acid mine drainage technology and several abatement methods including a description and an evaluation of potential abatement methods for acid drainage. Results of his investigations suggested that two abatement methods were feasible for treatment of acid drainage. These are: 1) neutralization using limestone in a revolving drum, and 2) mine flooding using an earthfill dam. He recommended pilot facilities be established on two mine discharges entering Sand Coulee. These facilities were never constructed nor other testing attempted.

Several organizations presently are working on abandoned mine problems in the Belt and Sand Coulee areas. The Montana Department of State Lands has an existing program to reclaim several abandoned coal mines in the Belt-Armington area and at least one old mine near Centerville. This program involves the removal and cleanup of the mine wastes adjacent to the adits and using these wastes to backfill old workings. After cleanup the areas will be contoured and reseeded.

The Montana Bureau of Mines and Geology is currently investigating discharging mines in the Sand Coulee area and has implemented a monitoring program to measure the quality and quantity of effluent from several selected mines and water in Sand Coulee Creek.

The Soil Conservation Service has a current program to investigate effects of mine drainage on the surrounding land under the Rural Abandoned Mine Program (RAMP). The objective of this program is to establish priorities for reclamation of the old mines and for mitigation of the polluting discharge. Presently the SCS is investigating Lewis Coulee near Belt to see if there are feasible abatement or correction measures for abandoned coal mine problems.

Acid Mine Drainage (AMD)

Acid mine drainage (AMD) is the result of the interaction of water and oxygen with pyrite contained in the coal and/or mine wastes exposed by previous mining activities. The chemical mechanism of AMD has been investigated and described by many investigators including the EPA (1975), Hill (1968) and Bams and Romberger (1981). The rate of the acid producing reactions also is enhanced by bacteria as described by Belly and Brock (1974) and Lovell (1981). The reactions of pyrite, water, oxygen and bacteria to form AMD are complex and not completely understood. The resultant of these reactions is well known and can be simply summarized. Pyrite is an iron sulphide mineral (FeS_2) that reacts with water and oxygen to produce sulfuric acid. The chemical reaction is:

$$2FeS_2 + 2H_2O + 7O_2 \longrightarrow 2FeSO_4 + 2H_2SO_4$$

Coal in the Sand Coulee and Belt areas contains significant concentrations of pyrite which typically exists as pyrite crystals in the coal and in fractures. Groundwater present in the coal or groundwater

percolating downward from the overlying Kootenai Formation migrates through the fractured coal and contacts the pyrite. Oxygen from air in the old workings then dissolves in the mine water and reacts with the pyrite to produce sulfuric acid. In addition to the production of AMD from groundwater, surface water in the form of precipitation and streamflow percolates through mine wastes in some areas and produces sulfuric acid.

The pH of the mine discharge in the study area ranges from about 2.0 to over six. Depending on the pH, the color of discharge varies from clear to yellow-orange or red. The yellow-orange and red colors results from the iron hydroxide which precipitates out of solution when the pH of the water increases to above 4.5.

When the pH is lower than 4.5, the ferric sulfate $Fe_2(SO_4)_3$ can be hydrolyzed increasing the acidity and preventing precipitation of iron. The more acid water generally is clear in color and the quality is deceiving because of its resemblance to fresh water.

Significance of AMD

Acid mine drainage from numerous abandoned coal mines has adversely effected the environment in both the Sand Coulee drainage and Belt Creek areas. The Belt area has a smaller number of discharging mines and a smaller quantity of total mine discharge than present in Sand Coulee; consequently, the environmental impacts at Belt are not as widespread as in the Sand Coulee drainage.

All of the AMD in the Belt area flows to Belt Creek. One obvious effect of AMD at Belt is the loss of land area along stream channels carrying acid water and a probable reduction in land values and building site potential adjacent to these streams. The contribution

of acid mine discharge also has reduced the quality of water in Belt Creek and has significantly increased the concentration of suspended solids, dissolved salts, and metals in the water. The effect on aquatic life has not been investigated, however AMD generally has degraded or completely destroyed the aquatic community. During late summer low flow and during years of less than normal streamflow, Belt Creek downstream from Belt has a small flow and is severely impacted by AMD.

The Sand Coulee drainage area has been significantly impacted by AMD. Streams, beginning about 10 miles south of Tracy and Sand Coulee Creek downstream to the Missouri River, are polluted by AMD. This area includes over 30 square miles and includes about 25 miles of stream channel (Figure 2). Six tributaries to Sand Coulee Creek are polluted. It also has been reported that AMD from Sand Coulee Creek affects the Great Falls Water Treatment Plant whose source of water is the Missouri River. Discussions with plant personnel (L. Lucken, pers. comm. August, 1981) indicated that flows from Sand Coulee Creek seldom reached the river and have little impact on the treatment plant.

Most of the streambeds and banks along tributaries of Sand Coulee Creek receiving AMD are highly discolored and devoid of vegetation from the accumulation of iron precipitate and acidity. The presence of mine wastes and the continued flow of the acid mine discharge has greatly reduced the aesthetics of the Sand Coulee area and probably has lowered the value of real estate in the drainage. In many instances land has been affected to the point of being totally unsuitable for any use. The accumulation of mine discharge has also created a large marsh at the base of a hillside northeast of Tracy and has damaged several acres of farmland. The size of the marsh is slowly expanding from the continued flow of discharge, resulting in the progressive loss of farmland.

It is reasonable to assume that some percentage of mine discharge, including contaminated runoff and seepage from polluted streams, percolates into the subsurface where it recharges groundwater in the alluvial aquifer along the Sand Coulee Creek flood plain and along Belt Creek. These aquifers are shallow and are a source of water to some households located along these streams. Local residents report contamination of groundwater along the drainages and the shallow alluvial aquifer is unsuitable in many places as a drinking water source.

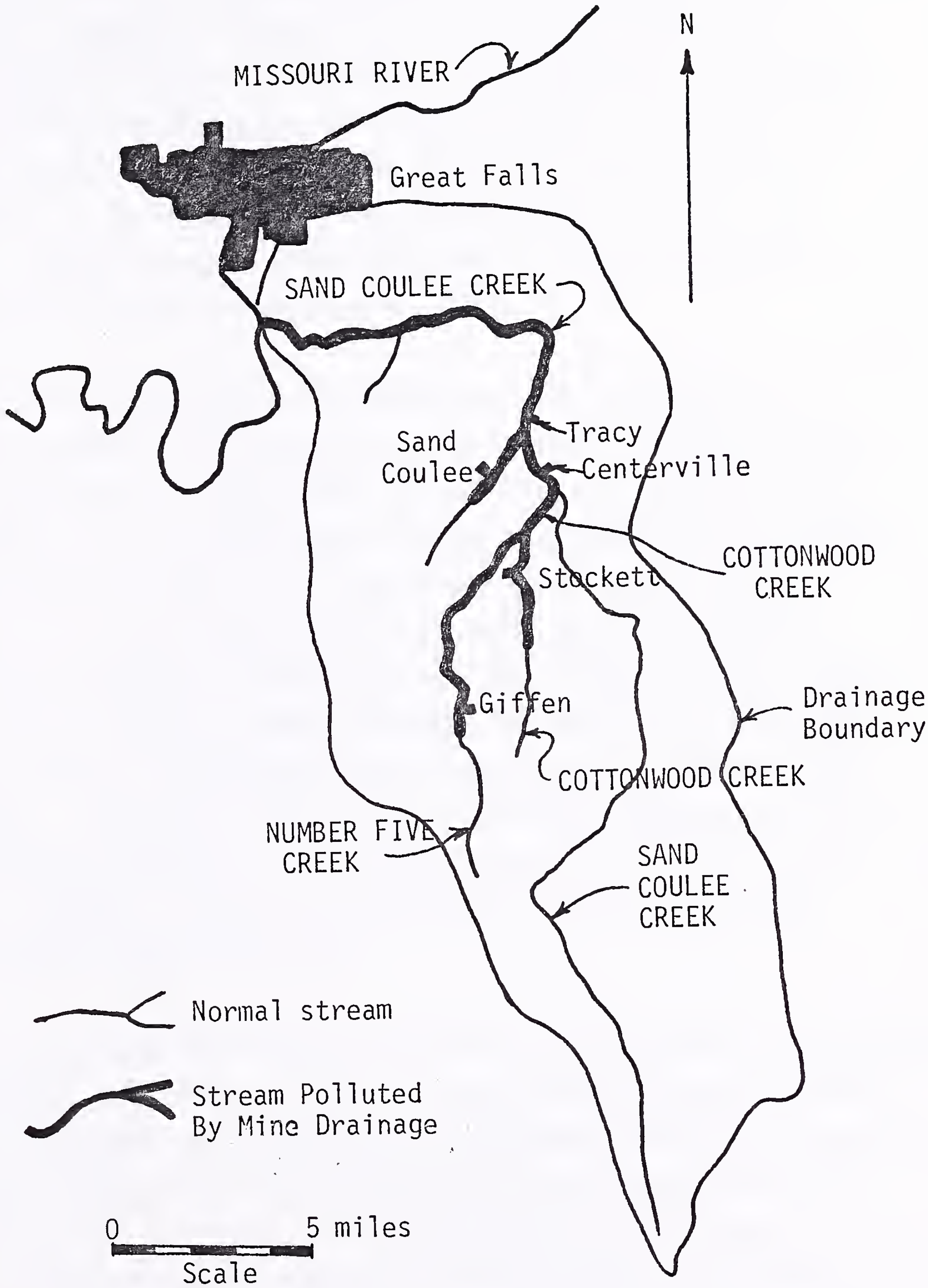


Figure 2. Map Showing Location of Streams Receiving Acid Mine Drainage Waste (after McArthur, 1970)

SAND COULEE DRAINAGE

The Sand Coulee area is in central Montana and is located approximately 10 miles southeast of Great Falls, Montana. The general study area consists of about 118 square miles contained in Townships 18, 19 and 20 North and Ranges 4 and 5 East (Figure 1 and Exhibit 1). Centerville, Stockett, Tracy, and Sand Coulee are located in the central portion of the study area along Sand Coulee Creek and its tributaries. Bedrock outcrop along the edges of the drainages are the site for most of the abandoned mine adits.

The area above the floodplain is primarily a large plateau that slopes gently northward away from the north flank of the Little Belt Mountains. Numerous small drainages directed toward the Sand Coulee floodplain have cut into the plateau leaving a dissected and irregular terrain above the drainages. The topography of the study area is gentle except along the incised drainages and along the floodplain edges where some bluffs and steep slopes occur. Most of these slopes are between 100 to 200 feet high; although, in many areas along upper Sand Coulee Creek and Cottonwood Creek, slopes are in excess of 300 feet in height. Elevation in the study area varies between 4100 feet along the southern boundary to 3400 feet along Sand Coulee Creek at the northern boundary. Average elevation for the area is between 3600 and 3700 feet above sea level.

Most of the area along Sand Coulee Creek and its tributaries is characterized by abandoned mine portals and mine wastes removed from the underground mines. Many of the hillsides are completely devoid of vegetation and are covered with piles of discarded coal and carbonaceous shale wastes. Most of the hillsides are blackish gray to red-orange in color due to coal and scoria wastes or iron hydroxide precipitates from AMD. Discarded mine equipment and debris left from the abandoned mining operations are scattered over much of the area.

The Sand Coulee drainage area was investigated to determine the location of abandoned coal mining operations and the existence and extent of acid mine discharge (AMD) from abandoned coal mines. To evaluate AMD and impacts to the environment adits emitting AMD were examined, drainage geology was mapped, and water resources were investigated including surface water, groundwater and water quality. Land and water resources impacts of AMD in the drainage were determined.

GEOLOGY

Geology of the Sand Coulee drainage has been investigated and described in several available reports including Goers (1968), Fisher (1909), Walker (1974) and Silverman and Harris (1967). For this investigation, surficial geology within the study area was of primary interest. Surficial geology is shown on Exhibit 2 and a composite stratigraphic column is in Figure 3.

The Sand Coulee drainage lies in the Great Falls-Lewistown Coal Field, which is a large deposit of sub bituminous coal extending southwest from Great Falls over 100 miles to Lewistown. Thickness of the coal seam varies from one to ten feet; however, the bed itself consists of several seams separated by thin shale partings. These shale partings are carbonaceous and often resemble the coal. The coal seams are lenticular, have a variable thickness throughout the coal field, and generally pinch out at the margin (Silverman and Harris, 1967).

Rocks exposed in the study area range in age from Paleozoic to Recent. The oldest rocks consist of a massive light-gray limestone with some thin dolomite inner beds. This limestone is part of the Mission Canyon Formation of the Mississippian Madison Group. The Mission Canyon limestone is exposed along Cottonwood Creek between Centerville and Stockett and along Sand Coulee Creek south of Centerville.

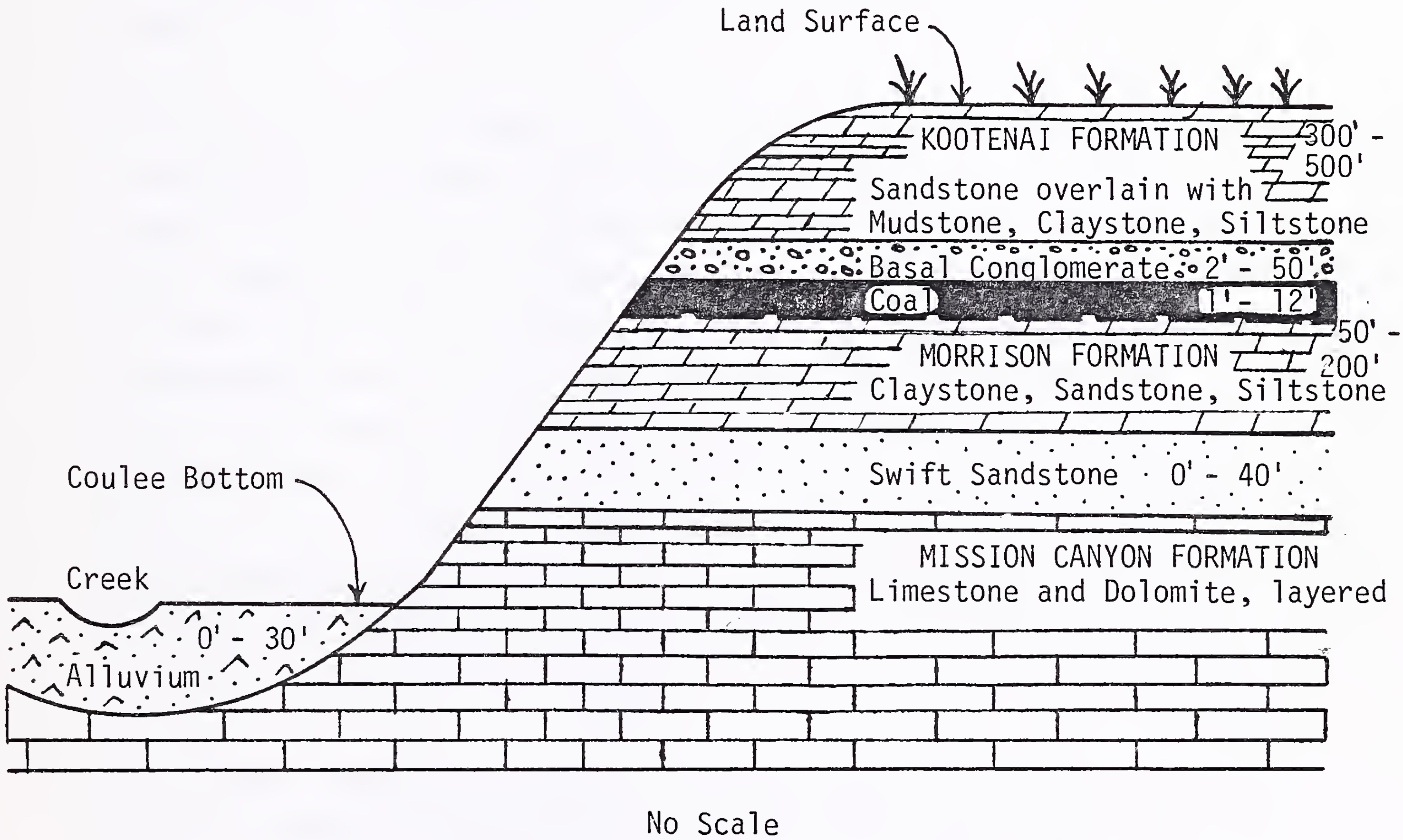


Figure 3. Generalized Cross-Section Showing Stratigraphy of the Sand Coulee Creek Drainage (after McArthur, 1970)

Overlying the Mission Canyon limestone is a massive, fine-grained strongly cemented sandstone that is light gray to pale orange in color. This is the Swift Formation of the Upper Jurassic Ellis Group. The Swift ranges in thickness from 0 to 40 feet and is exposed above the Mission Canyon Formation along Cottonwood and Sand Coulee Creeks. The Swift Formation disconformably overlies the folded and channeled surface of the Mission Canyon Formation (Goers, 1968).

Overlying the Swift Sandstone is the Morrison Formation of Upper Jurassic age. The Morrison is a thick-bedded, light to medium gray-green colored mudstone with some interbedded light gray limestone and pale orange colored sandstone in the lower part of the formation. The upper part of the formation consists of a medium to dark gray carbonaceous shale which is separated from the lower mudstone by a light gray limestone. The top of the Morrison above the shale contains the coal seam that is the focus of mining in this area (Silverman and Harris, 1967 and Walker, 1974). Above the coal is a thin, black, carbonaceous shale layer. The Morrison Formation varies in thickness from 50 feet to over 200 feet in the Sand Coulee area and is exposed along hillsides adjacent to Sand Coulee and its tributaries.

The Kootenai Formation of Lower Cretaceous age is present at the land surface in much of the study area and forms the steep slope along Sand Coulee and its tributaries. The Kootenai is a massive and competent sandstone with alternating layers of massive mudstone. The base of the Kootenai consists of a conglomeritic sandstone which defines the contact boundary between the Kootenai and Morrison formations. The basal conglomerate of the Kootenai varies in thickness from 30 to over 70 feet. Above the basal conglomerate are several beds of sandstone, mudstone, and some thin limestone layers. These beds vary in thickness from a few feet to 50 feet or more. The lower Kootenai section in the study area ranges in thickness from less than 10 feet upwards to about 250 feet and is a distinct light red-orange to red-brown color. The entire thickness of the Kootenai varies from 300 to 500 feet in the Sand Coulee study area.

Although it is not exposed in the study area, the Blackleaf Formation of the Lower Cretaceous Colorado Group underlies the hills west of the Sand Coulee drainage. The Blackleaf consists primarily of interbedded sandstone and shale of variable thickness.

The drainage bottom along Sand Coulee Creek from Centerville to the northern boundary of the study area consists of Quaternary alluvium. This alluvium consists of unconsolidated sand and gravel deposited mainly by Sand Coulee Creek. The more extensive alluvium near the town of Tracy and northward was probably deposited by the ancestral Missouri River. There are several sites along the north limit of the Sand Coulee study area that are used as gravel pits. Thickness of alluvium is not known however, well logs suggest the alluvium is thin along the southern portion of Sand Coulee Creek and reaches a maximum thickness of over 30 feet north of Tracy.

Coal

The coal seam of the Morrison Formation is extensive and is present at various depths throughout most of the area between Great Falls and Lewistown. Coal in the study area is contained primarily in one seam of three beds, separated by carbonaceous shale layers. The coal seam, as described by Silverman and Harris (1968), varies in thickness from 1 foot up to 12 feet. Overburden varies from less than 50 feet to over 500 feet.

The coal is ranked as sub bituminous B to high volatile C bituminous and contains up to 4 percent sulphur. The BTU content (heating value) averages over 11,000 BTU per pound which is above average for most Montana coals and is desirable as an energy source. A typical coal analysis is in Table 1. Because of its high sulphur content; however, the coal from the Great Falls-Lewistown Coal Field has a lower marketing potential than the lower BTU and low sulphur coal of the Fort Union Formation of southeastern Montana.

TABLE 1. TYPICAL COAL ANALYSES FROM GREAT FALLS COAL FIELD

	Ave.	Range
BTU/lb.	11,118	86% to 12,000
Ash	19.13%	12.7% - 30.2%
Volcanic Matter	28.79%	22.7% - 34.8%
Fixed Carbon	52.07%	47.1% - 57.8%
Sulphur	2.7%	0.5% - 5.5%

Source: Silverman and Harris (1968).

Coal reserves in the Sand Coulee and Belt Creek areas are estimated to be over 320 million tons. During the period between 1885 to 1955 the coal mined from the Great Falls-Lewistown Coal Field exceeded 36 million tons. This amounted to about 23 percent of the total coal produced in Montana during that period. Coal mined from the Great Falls-Lewistown area from 1955 to 1965 was less than 1 percent of the total coal produced in Montana and, from 1965 on there has been no commerical coal production.

Geological Structure

The Sand Coulee area lies in the Great Falls-Lewistown coal field, which is a large structural basin located between the Rocky Mountain Overthrust Belt to the west and the Central Stable Platform to the east. Most of the area is essentially flat with minor dipping or almost horizontal strata. Along the western and southern portion of the Central Platform lies an area of intensely folded and warped strata. Most important of these major folds are the Sweetgrass Arch which extends along the southwest edge of Great Falls northward into Canada and the major uplift of the Little Belt Mountains which are located east and south of the Sand Coulee area. The Sweetgrass Arch is

considered to be a northwest extension of the Little Belt Mountain uplift (Goers, 1968). Although most of the area of the Central Platform is fairly flat with only several hundred feet of relief caused by stream erosion, the uplifted area which is somewhat rectangular in pattern, rises to several thousand feet above the plains.

Regional dip in the Sand Coulee-Belt Creek area is gentle with strata dipping northward from 3 to 6 degrees (Silverman and Harris, 1967). The uplifted area has some steeply dipping beds ranging from 60 to 80 degrees to almost vertical along the north and south extremes of the uplift. Strata lying across the uplifted and folded beds are again relatively flat with dips varying vetween 3 to 10 degrees.

There are no major faults noted or reported in the study area. Many small normal faults are present in the domes located along the flanks of the mountains produced by the uplift, and several minor faults have caused small displacements in the localized strata of the general area. Displacement is usually only a few feet, although a normal fault north of Stockett has created a 15 foot displacement in the Mission Canyon Formation.

HYDROLOGY

The entire Sand Coulee area is drained by Sand Coulee Creek and its tributaries. Groundwater is present in the drainage in numerous formations and is widely used for stock, domestic and public water supply purposes. Acid drainage from the abandoned coal mines has had significant impacts on both surface water and groundwater resources in the drainage.

Surface Water

The Sand Coulee Creek drainage (195 square miles) is in the south central portion of Cascade County, Montana and is part of the upper Missouri River Basin. Ninety square miles of the drainage contain abandoned and inactive coal mines which discharge acid mine water

(Exhibit 1). Sand Coulee Creek originates along the north flank of the Little Belt Mountains about 28 miles south of Great Falls at an elevation of about 7,000 feet. The creek flows generally northward through the towns of Centerville and Tracy and then turns westward before discharging to the Missouri River approximately three miles upstream of the Great Falls Water Treatment Plant at an elevation of 3300 feet. Sand Coulee Creek has a total length of about 35 miles.

Sand Coulee Creek is an intermittent stream with highly variable flows which are dependent upon seasonal precipitation and snowmelt. Peak flows occur in late spring and early summer in response to spring runoff from snowmelt and rainfall. Low flows occur in late summer, fall and winter and the stream is often dry during this period in years of below average precipitation. Floods are common along Sand Coulee Creek during spring runoff resulting in occasional crop damage. Flooding occurred in 1884, 1899, 1908, 1927, 1936, 1953, 1958, 1964, 1965, 1966, 1967, and 1975 (SCS, 1973). Streamflow measurements for the Sand Coulee drainage are summarized in Table 2. The primary purpose of this investigation was a study of discharging mines and streamflow data collection was limited.

Major tributaries to Sand Coulee Creek are Spring Coulee, Walker Coulee, Antelope Coulee, Sand Coulee, Cottonwood Creek and Number Five Coulee. Many smaller tributaries and coulees provide flow to Sand Coulee Creek during spring runoff and during periods of intense rainfall. Cottonwood Creek, Sand Coulee and Number Five Coulee are the only major tributaries within the study area boundary. These tributaries probably account for over 50 percent of the flow after spring runoff. These tributaries, however, are fed almost entirely by mine discharge during late summer and fall.

On July 13-14, 1981, Sand Coulee above its confluence with Cottonwood Creek was flowing at an estimated 25 cfs after receiving runoff from about 0.43 inches of precipitation. Below the confluence with Cottonwood

TABLE 2. STREAMFLOW MEASUREMENTS FOR THE SAND COULEE CREEK DRAINAGE NEAR SAND COULEE, MONTANA

Station	Description	Location	Streamflow - Gallons Per Minute (gpm)						
			1981	1980	1969 [1]				
			7/13	8/15	8/1	9/1	10/1	11/1	12/1
SS2	Sand Coulee Creek just below confluence with Cottonwood Creek	19N05E19AAC	20,000 est.		2750	1100	600	650	250
SS5	Sand Coulee Creek between Sand Coulee and Tracy, Montana, at mouth	19N04E12DCA			750	500	400	300	100
SS6	Cottonwood Creek above confluence with Number Five Coulee	19N04E25DAB		115					
SS7	Number Five Coulee above Cottonwood Creek	19N04E25DAB		225					
SS8	Sand Coulee Creek above confluence with Cottonwood Creek	19N05E19AAC	11,000 est.						
SS11	Sand Coulee Creek at Johnson Farm	19N05E6CBD		Dry		1500			
SS14	Upper Giffen Coulee	18N04E22DBA		135					

(1) Data from McArthur, 1970.

Creek, the flow of Sand Coulee Creek had increased to an estimated 45 cfs. Of the estimated 20 cfs flowing in Cottonwood Creek, less than 1 cfs was contributed by discharging mines.

Number Five Coulee. Number Five Coulee has a drainage area of about 25 square miles and originates from the confluence of several smaller drainages along the face of the plateau north of the Little Belt Mountains and about 8 miles south of Stockett. Tributaries to Number Five Coulee include Dutchman Coulee and Giffen Coulee. Number Five Coulee flows through the Giffen Mine area and receives the discharge from the Giffen Mine (SCM 4). Number Five Coulee discharges to Cottonwood Creek about one mile north of the town of Stockett.

Water quality samples from Number Five Coulee above and below the Giffen Mine (SCM 4) (Table 3 and Exhibit 1) shows the quality of water above the mine discharge is good but is severely degraded by acid drainage discharged from the Giffen Mine. Waters in Number Five Coulee above the Giffen Mine (SS14) have a pH of 6.8, a specific conductivity of 650 μmhos/cm and a sulfate concentration of 36 mg/l. Below Giffen Mine (SS7) the pH is 5.5, specific conductivity is 940 μmhos/cm and sulfate 600 mg/l.

Cottonwood Creek. Cottonwood Creek has a drainage area of about 12 square miles and originates in the foothills about five miles south of Stockett. The creek flows generally northward through Stockett and continues another three miles to its confluence with Sand Coulee Creek at the northwestern edge of the community of Centerville. Cottonwood Creek receives flow from several small intermittent streams and small springs and from Number Five Coulee. Water discharged from mine SCM 9 flows into Cottonwood Creek about one mile southeast of Stockett. Because of its generally small discharge, mine SCM 9 is not considered a significant source of water to Cottonwood Creek; however, flow from the mine is continuous. Flow measurements made on August 15, 1980, showed that SCM 9 was contributing only 10 percent of the total flow of Cottonwood Creek on that date.

TABLE 3--SUMMARY OF WATER QUALITY SAMPLING - SAND COULEE Surface Water

SAMPLING SITE	M ABV S COULEE	M BLW S COULEE	SS5	SS6	SS7	SS13	SS14
SAMPLE DATE	11/28/80	11/28/80	08/15/80	08/15/80	08/15/80	08/15/80	08/16/80
NICKEL (NI) DISS	<0.03	<0.03	4.00	0.04	0.14	5.60	<0.03
SELENIUM (SE) TOTAL			0.005	<0.005	<0.005	0.006	<0.005
SELENIUM (SE) DISS	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
SILVER (AG) TOTAL			<0.005	<0.005	<0.005	<0.005	<0.005
SILVER (AG) DISS	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
ZINC (ZN) TOTAL			14.1	0.07	0.03	22.2	0.01
ZINC (ZN) DISS	0.01	<0.01	13.8	0.01	0.02	21.3	<0.01
OTHER PARAMETERS							
BORON (B)	0.13	0.14	0.53	<0.10	<0.10	0.74	<0.10
SILICA (SIO2)	21.4	22.3	134.8	7.4	6.8	175.4	12.8

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 3-SUMMARY OF WATER QUALITY SAMPLING - SAND COULEE Surface Water

SAMPLING SITE	M ABV S COULEE	M BLW S COULEE	SS5	SS6	SS7	SS13	SS14
SAMPLE DATE	11/28/80	11/28/80	08/15/80	08/15/80	08/15/80	08/15/80	08/16/80
PHYSICAL PARAMETERS							
SPEC. COND. UMHOS/CM LAB	370	350	4200	1300	940	5300	650
TURBIDITY (JTU) LAB	5.5	3.9	35	86	5.5	2.4	32
PH LAB	7.7	7.8	2.6	7.6	7.2	2.4	6.8
TOTAL SUSP. SOLIDS	20	15	55	76	5	15	25
TOTAL DISS. SOLIDS MEAS.	218	206	4560	866	858	5800	348
COMMON IONS							
CALCIUM (CA)	41	35	240	137	160	430	47
MAGNESIUM (MG)	13	13	137	73	45	168	48
SODIUM (NA)	19	19	22	56	18	21	25
POTASSIUM (K)	4	4	2	6	7	0	5
ACIDITY AS CACO3			3510			4380	
BICARBONATE (HCO3)	167	167	0	284	46	0	363
CARBONATE (CO3)	0	0	0	0	0	0	0
SULFATE (SO4)	46	42	4070	325	600	5120	36
CHLORIDE (CL)	11	9	65	127	6	59	6
FLUORIDE (F)	0.74	0.74	<0.1	0.55	0.99	<0.1	1.3
NUTRIENTS							
AMMONIA (NH4-N)	0.11	<0.1	1.6	0.71	0.22	0.22	0.24
NITRATE + NITRITE AS N	0.19	0.19	0.06	2.1	0.47	0.18	3.2
TRACE METALS							
ARSENIC (AS) TOTAL			0.14	<0.005	<0.005	0.22	0.012
ARSENIC (AS) DISS	0.019	0.017	0.14	<0.005	<0.005	0.22	<0.005
ALUMINUM (AL) TOTAL			317	1.1	0.1	395	0.2
ALUMINUM (AL) DISS	0.2	<0.1	266	0.1	<0.1	325	0.2
CADMIUM (CD) TOTAL			0.055	<0.001	<0.001	0.061	<0.001
CADMIUM (CD) DISS	0.001	<0.001	0.047	<0.001	<0.001	0.055	<0.001
COPPER (CU) TOTAL			0.17	<0.01	<0.01	0.78	<0.01
COPPER (CU) DISS	<0.01	<0.01	0.17	<0.01	<0.01	0.77	<0.01
CHROMIUM (CR) TOTAL			0.22	0.02	<0.02	0.22	<0.02
CHROMIUM (CR) DISS	<0.02	<0.02	0.22	<0.02	<0.02	0.21	<0.02
IRON (FE) TOTAL			550	1.1	0.37	460	0.32
IRON (FE) DISS	0.23	0.14	530	0.5	0.03	450	0.10
LEAD (PB) TOTAL			0.07	<0.01	<0.01	0.11	<0.01
LEAD (PB) DISS	<0.01	<0.01	0.07	<0.01	<0.01	0.11	<0.01
MANGANESE (MN) TOTAL			3.24	0.14	0.49	9.80	0.06
MANGANESE (MN) DISS	0.02	0.03	3.25	0.14	0.49	10.2	0.02
MERCURY (HG) TOTAL			<0.001	<0.001	<0.001	<0.001	<0.001
MERCURY (HG) DISS	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
MOLYBDENUM (MO) TOTAL			0.009	<0.005	<0.005	0.014	<0.005
MOLYBDENUM (MO) DISS	<0.005	<0.005	0.009	<0.005	<0.005	0.013	<0.005
NICKEL (NI) TOTAL			4.87	0.04	0.14	5.60	<0.03

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

Water quality in Cottonwood Creek above its confluence with Number Five Coulee (SS6 in Table 3) shows Cottonwood Creek to have high concentrations of dissolved solids and metals and a low pH.

Sand Coulee. Sand Coulee (also referred to as the Rusty Ditch and No Name Creek) is the major tributary of Sand Coulee Creek. Sand Coulee originates in the foothills about four miles southwest of the town of Sand Coulee and joins Sand Coulee Creek at Tracy. The drainage area of Sand Coulee is about seven square miles.

Sand Coulee is entirely spring fed above the abandoned mines but has little flow until it receives water discharging from abandoned mines. There are five mine discharges into Sand Coulee. These are SCM 2, SCM 3, SCM 5, SCM 6 and SCM 11. Additional flows are contributed by Mining Coulee and by Kate's Coulee. It is unusual that the drainage with the smallest area contains the greatest number of discharging mines. The combined flows of these mines account for between 25 and 60 percent of the total mine discharges in the Sand Coulee drainage area. One possible explanation is less surface water runoff and greater infiltration during precipitation events. Since discharges from these mines increases and decreases almost directly in response to precipitation events, a rapid and direct connection of precipitation with the underground mine workings is probable. About 80 acres of land adjacent to Sand Coulee, one mile upslope from SCM 2 is strip-farmed. This land may be allowing a greater percentage of the precipitation to infiltrate into the sub surface.

Quality of water in Sand Coulee is extremely poor and closely resembles quality of mine effluent. Analysis of a sample taken from Sand Coulee (Table 3) shows the waters to have a pH of 2.6, a specific conductivity of 4200 μmhos/cm, acidity of 3510 mg/l, sulfate of 4070 mg/l, and high concentrations of aluminum, manganese and zinc.

The Missouri River receives discharge from Sand Coulee Creek. Due to infiltration, water from Sand Coulee Creek normally does not reach the river. Quality of water in the Missouri is good (Table 3) and the dilution capability of this river is so great that Sand Coulee Creek has no measurable impact on river water quality.

The Montana Department of Health and Environmental Sciences has developed classifications for all streams in Montana. Sand Coulee Creek and its tributaries are classified as a B-1 stream (Section 16.20.618, Surface Water Quality Standards). This classification states:

> Waters classified B-1 are suitable for drinking, culinary and food processing purposes, after conventional treatment; bathing, swimming and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.

Waters in the Sand Coulee Creek drainage that are affected by AMD will not meet the B-1 classification. Low pH, high concentrations of salts and metals, and low dissolved oxygen all violate the B-1 classification.

Mine Effluent Discharge

Over 100 mine adits were located in the Sand Coulee drainage area using recent aerial photographs and U. S. Geological Survey quadrangle maps. Most of these adits are shown on Exhibit 1 and all of the adits were investigated during the summer of 1980 to determine the existence of water discharges from the adits. Ten of the 100 adits investigated were discharging effluent (Exhibit 1). It was apparent that discharge from these mines had occurred for many years. McArthur (1970) reported locating a total of 112 old mine entrances in the Sand Coulee area. Of these 112 mines, twenty two were discharging acid mine water during his study in the summer of 1969. Only nine of the mine adits, however, produced acid discharge continuously during his study period. The remaining thirteen mines showed evidence of intermittent discharge only. Eight of the nine mines producing continuous discharge during McArthur's study are still discharging and are part of the mines investigated (Table 4). A correlation between Hydrometrics site designations and those of other previous and on-going investigations is in Table 5. Mine 36-2 in McArthur's report, is located near Cottonwood Creek. This mine has stopped flowing entirely and Mine 7-8 (SCM 15) is described by McArthur as having intermittent flow discharged continuously during this study. Another mine near the town of Sand Coulee 13-6 (SCM 11) which had continuous flow during McArthur's investigation has had only intermittent discharge during this study.

During April 1981, the mine adits were reinvestigated to determine if any additional mines were discharging or if the discharge from the initial ten mines has changed as a result of spring runoff. In April 1981, only nine of the original ten adits were discharging effluent and no new mine flows appeared. Mine SCM 11 had stopped discharging during the unusually dry winter. Mine SCM 11 began discharging again in May 1981 after considerable precipitation had occurred.

The ten mines producing continuous discharge through 1980-1981 were investigated in greater detail as these mines have the greatest

TABLE 4. PHYSICAL CHARACTERISTICS OF COAL MINES IN THE SAND COULEE AREA

Mine Number and Name	Location	Mine Size	Volume of Mine Waste Present	Extent Subsidence Areas	Mine Adit Elev. (MSL)	Resource Impacted
SCM 2 Carbon	19N04E23ADCB	L	M	M	3580	SW Qual & Quan GW Quality
SCM 3 Carbon	19N04E23ADAB	L	M	M	3560	SW Qual & Quan GW Quality
SCM 4 Giffen	18N04E14ACD	L	L	L	3920	SW Qual & Quan GW Quality
SCM 5 Brown	19N04E14DDCD	M	M	0	3530	SW Qual & Quan Esthetic Value
SCM 6 Nelson	19N04E13CBD	M	L	S	3520	Esthetic Value
SCM 7	19N05E7ABD	S	S	S	3450	Agr. Lands
SCM 8	19N05E7CACD	M	M	0	3490	GW Quality
SCM 9 Number 6	18N05E6CDB	S	S	S	3870	GW Quality
SCM 11	19N04E13CBA	S	S	0	3520	GW Quality
SCM 15	19N05E7AAAA	S	0	0	3460	Agr. Lands

Notes: All mines located in Cascade County, Montana
Elevations taken from USGS topographic maps (Southeast Great Falls and Stockett, Montana 7.5 minute quadrangles)
0 = none, S = small, M = medium, L = large,
Qual = quality, Quan = quantity, SW = surface water,
GW = groundwater.

TABLE 5. CORRELATION OF MINE DESIGNATIONS USED IN THE SAND COULEE DRAINAGE

Site Number & Location (Hydrometrics)	Site Description	Designation Correlation McArthur[1]	MBMG[2]	State Designation
SCM 2 19N04E23ADCB	Upper Carbon Mine	23-6	AS-01	7-49
SCM 3 19N04E23ADAB	Lower Carbon Mine	23-5	AS-02	7-49
SCM 4 18N04E14ACD	Giffen Mine	14-1G		7-20
SCM 5 19N04E14DDCD	Brown Mine	14-1		7-48
SCM 6 19N04E13CBD	Nelson Mine	13-3		7-48
SCM 7 19N05E7ABD	Bad water Johnson Mine	7-9		7-42
SCM 8 19N05E7CACD	Tracy Mine	7-2	CS-01	7-40
SCM 9 18N05E6CDB	Number 6 Mine	6-1	CS-09	7-47
SCM 11 19N04E13CBA		13-6	AS-06	7-32
SCM 15 19N05E07AAAA	Good water Johnson Mine	7-8		7-41

1 McArthur (1970)

2 Montana Bureau of Mines and Geology unpublished data

3 Montana Department of State Lands

environmental impact. A monitoring program measuring the quantity and quality of the discharging effluent was conducted on these mines. In addition, the area adjacent to and surrounding the mine adits was investigated and described and the condition of the adit portal examined.

Flow measurements for all ten discharging mines in the Sand Coulee area are in Table 6. These measurements include the mines monitored by McArthur during his study in 1969 and 1970 and represent a time span of twelve years. Flow measurements recorded by the Montana Department of State Lands in 1979 and by Hydrometrics and the Montana Bureau of Mines and Geology in 1980 and 1981 also are tabulated in Table 5.

Table 6 shows the large variations in mine discharge during the course of a year and clearly illustrates the correlation between precipitation periods and increased flow. Figure 4 shows increased discharges from mines in May and June of 1981 after a 35 day period of almost constant precipitation which totaled over 6.10 inches beginning May 8, 1981, and ending June 18, 1981. Figures 5 and 6 show the exceptionally heavy precipitation recorded in Great Falls and also at a rain gauge installed at John Mittal's residence in Sand Coulee for the period April 1981 through July 1981. It is easy to see the effect of precipitation on mine discharge rates and the rapid response to measurable rainfall periods. Of the discharging mines in the Sand Coulee area, Mines SCM 2, SCM 6, SCM 8 and SCM 9 showed the greatest increase in flow rates. SCM 9 showed the greatest percentage increase for the monitoring period increasing from 11 gpm on April 3, 1981, to 166 gpm on June 13, 1981, an increase of over 1500 percent. Mine SCM 8 showed the most immediate response to precipitation and the rapid increases and decreases in the mine effluent fairly well reflects precipitation occurrences as does Mines SCM 5, SCM 6, and SCM 11. A comparison of precipitation events with mine effluent rates suggest that reponse time varies from almost immediate (Mines SCM 5, 6, 8, & 11) to several days or more for Mines SCM 2 and SCM 4. Mines SCM 3 and SCM 7 showed little change in

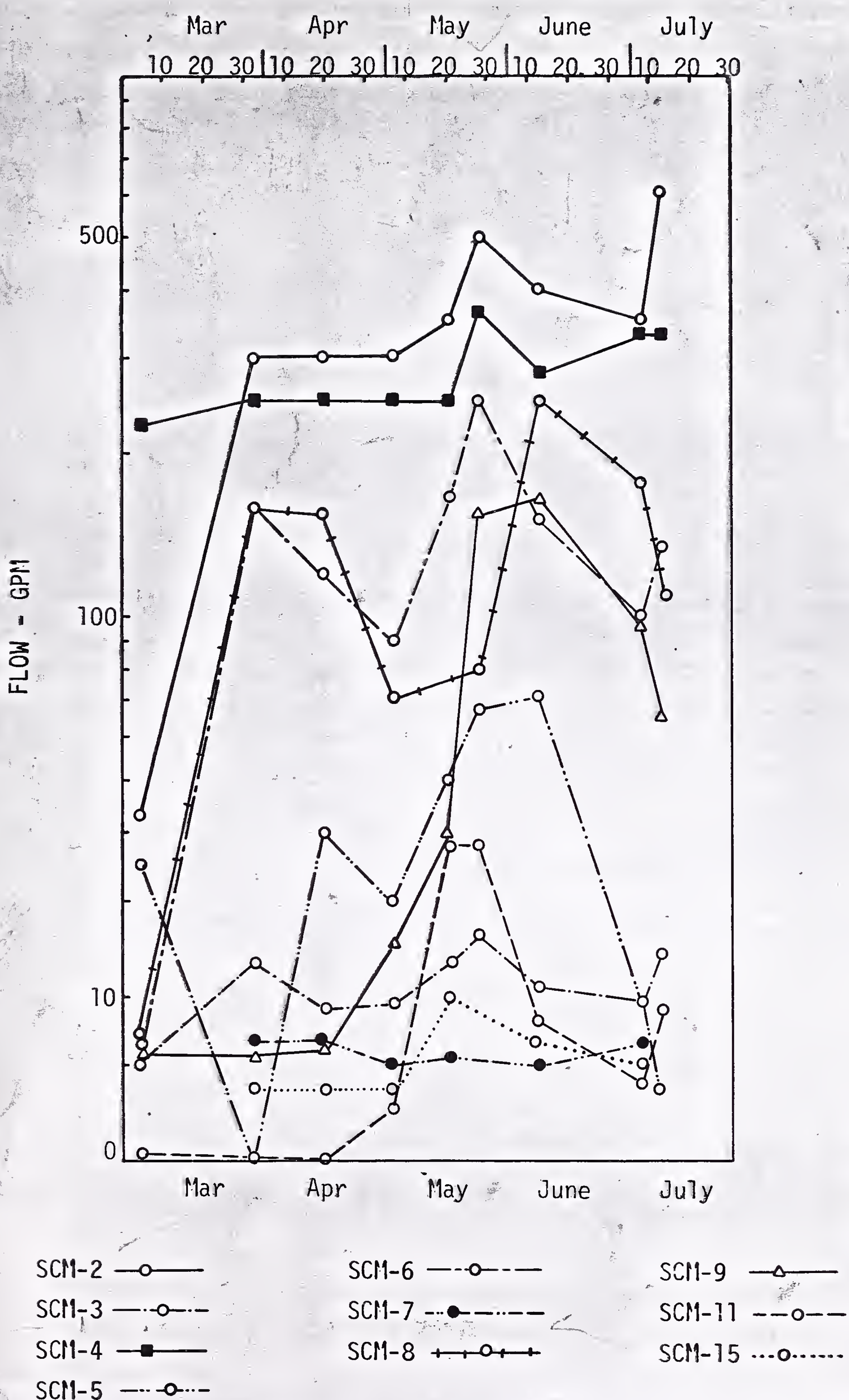


Figure 4. Discharge Measurements for Mine Discharges in the Sand Coulee Creek Drainage for 1981

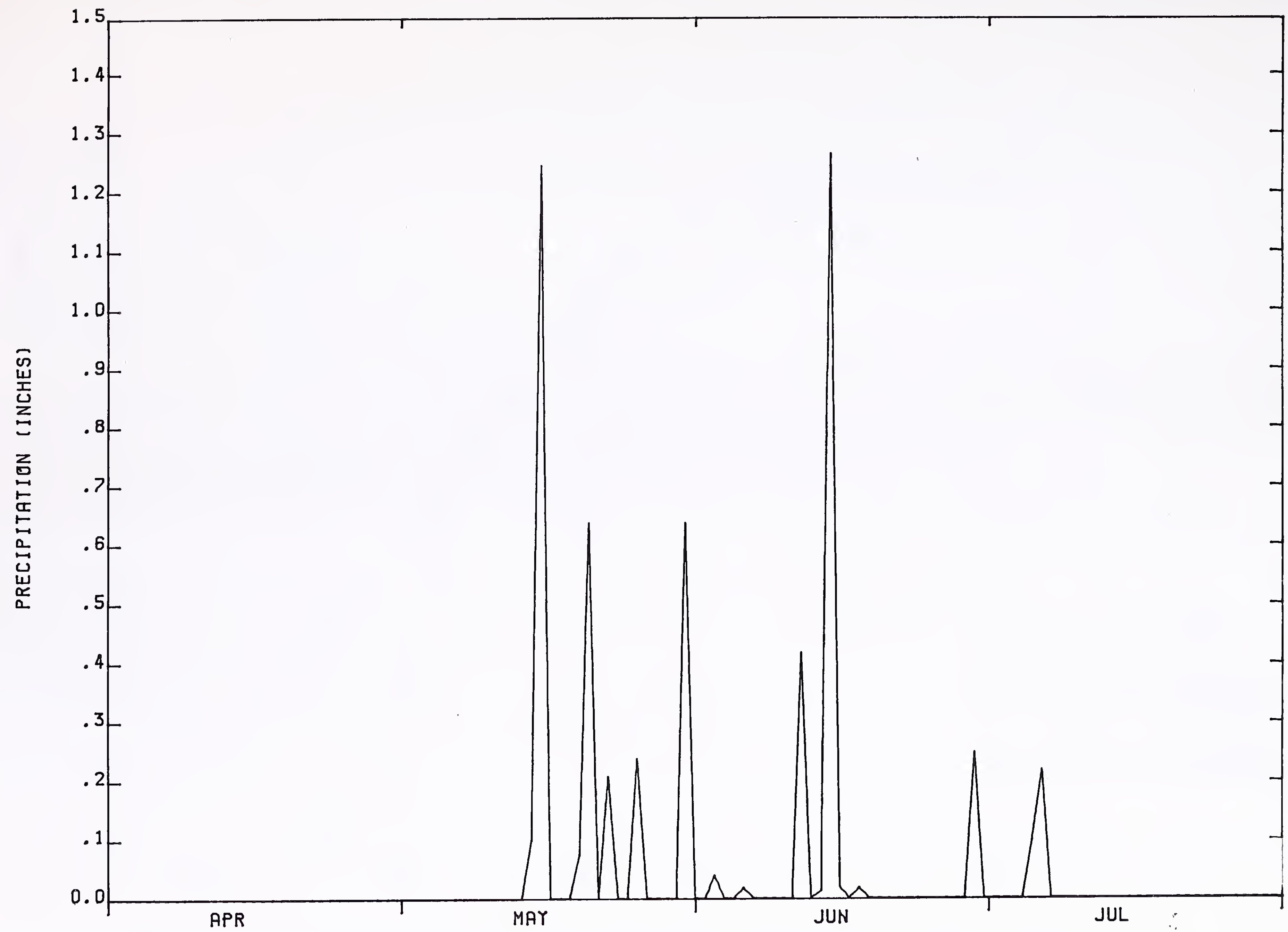


FIGURE 5 . 1981 DAILY PRECIPITATION FOR THE SAND COULEE AND BELT, MONTANA DATA FROM THE JOHN MITTAL RAIN GAUGE.

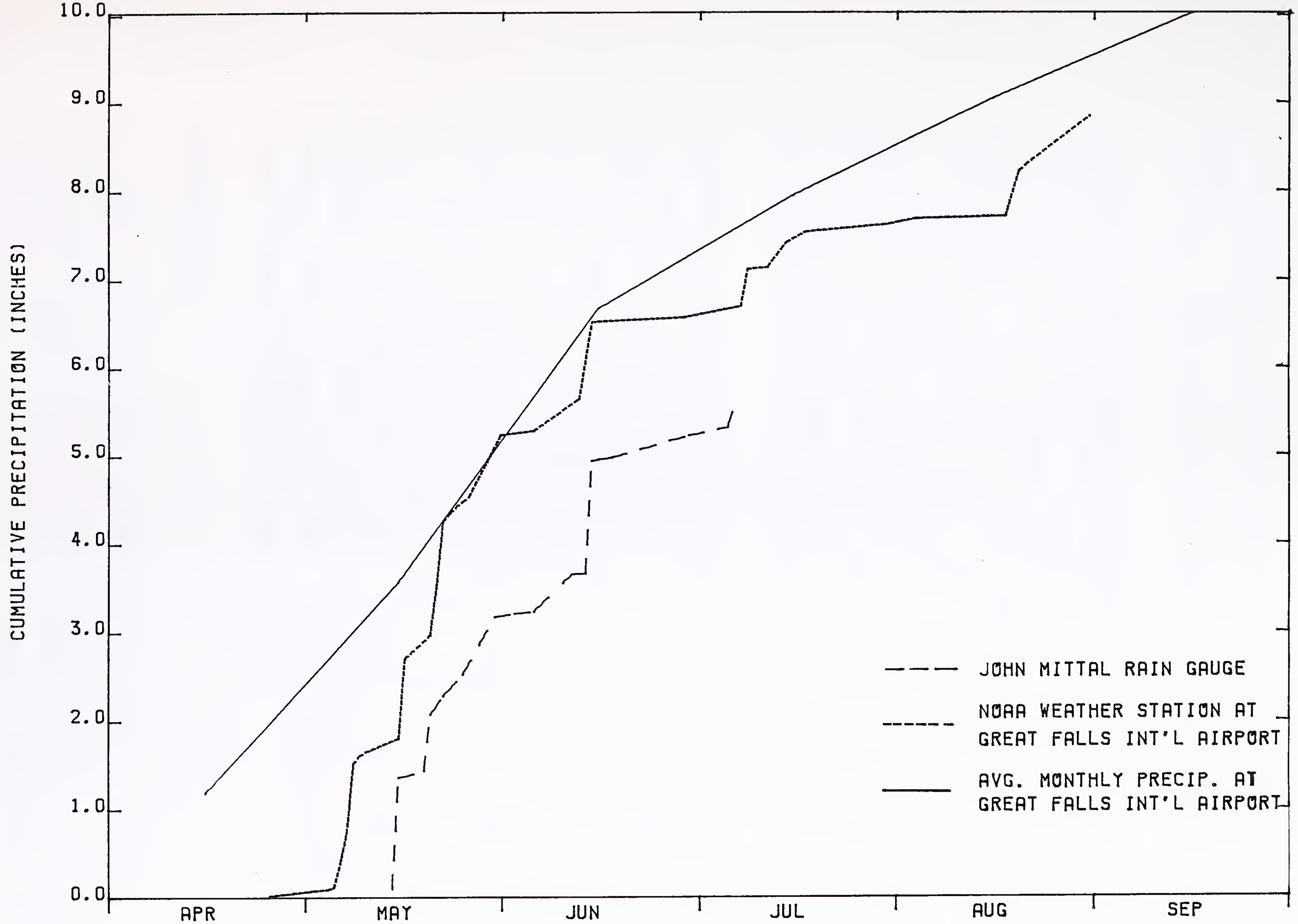


FIGURE 6 . 1981 CUMULATIVE PRECIPITATION FOR THE SAND COULEE AND BELT, MONTANA

flow rate during the monitoring period and the continuous recorder placed at discharging point of Mine SCM 7 exhibited little fluctuation in the discharge during periods of measurable precipitation.

A summary of the total amount of discharge from the mines in Sand Coulee is shown at the bottom of Table 6. The total mine effluent varies from a low of 350 gpm on March 5, 1981, to a high of 1500 gpm on May 28, 1981. The flow from mine SCM 2 was probably closer to 1000 gpm than the 500 gpm listed, thus it is probable that total flow at the end of May was almost 2000 gpm. Examination of mine effluent flows show a gradual decrease in early spring with an accelerated increase in late spring and early summer, which, coincides with spring runoff and the spring rainfall period. The decline in mid and late summer again reflects a reduction in the amount of precipitation.

A comparison of the individual and total mine discharge measurements for the period of McArthur's study with the current monitoring period show a similarity between total flow rates and variations. There does not appear to be a detectable change in the quantity of flow which would indicate a gradual decline in mine effluent rates over the last twelve years. What differences are apparent are probably more indicative of the time of the year the measurement was taken and/or the amount of precipitation for that year. The estimated total flow of 900 to 1000 gpm in July 1970 is close to the total flow of 1125 gpm measured July 8, 1981. At this time, information collected on mine discharge does not clearly indicate a trend towards an increase or a decrease in mine effluent with time. Figure 7 summarizes all available flows recorded on discharging mines.

Water Quality

The overall quality of water discharging from mines in the Sand Coulee drainage ranges from fair to very poor. Nearly all the mine effluent has low pH, high specific electrical conductivity, and high concentrations of sulfate, acidity, and metals, particularly iron and zinc. Water quality data for the ten discharging mines

TABLE 6. SUMMARY OF FLOW MEASUREMENTS FOR MINES IN THE SAND COULEE DRAINAGE, MONTANA

(All Flows are in Gallons Per Minute)

	1981													
Mine Site	3/5	4/3	4/7	4/12	4/13	4/14	4/15	4/20	5/8	5/14	5/18	5/21	5/28	6/13
SCM-1														
SCM-2	43	300						300 est.	300 est.			350 est.	500 est.	400 est.
SCM-3	10.2	23						18	19			23	26	21
SCM-4	225	250						250	250			250 est.	359	278
SCM-5	35	0						40	31			50	67	71
SCM-6	12.5	160						120 est.	90			165	250	150
SCM-7		13	12	14	12	11	13.8	13	10.5	15.3	11	10 est.		8
SCM-8	14.3	160 est.						155	71			350 est.	80	250
SCM-9	10.7	11						12	25			40	155	166
SCM-11	0.7	0						0	5			38	38	16
SCM-15		6 est.						6 est.	7			25 est.		13
TOTALS	351	923 est.						914 est.	808.5 est.			1301 est.	1475 est.	1373 est.

TABLE 6 . - Continued

(All Flows are in Gallons Per Minute)

Mine Site	6/17	6/22	6/25	1981 7/5	7/7	7/8	7/13	1980 8/14	9/21	1979 10/9	10/18	1970 3/23	7/22	1969 9/6	10/18
SCM-1													20	20	
SCM-2						350	600	114	103			45	135		150
SCM-3						19	7.2	16	7				20	20	
SCM-4						330	329	224	150	150 est.	150	300 est.	500	300 est.	300 est.
SCM-5						19	24	15	29			30	75	55	75
SCM-6						100	133	1.8	40				25	45	40
SCM-7	7.4	7.9	9.0	10.3	13.9	3 est.		1.4			15 est.	5	30		
SCM-8						178	109	19	20		15 est.	20	45	60	40
SCM-9						96	65	12	10	8 est.	8 est.	15	20	25	
SCM-11						7.5	17.9	5	2 est.						
SCM-15						10		5		10 est.	10 est.				
TOTALS						1112.5 est.	1285.1	413.2	361 est.			415 est.	870	525	605

9/21/80, 3/5/81, 5/28/81 & 7/31/81 data from Montana Bureau of Mines and Geology
10/9/79, 10/18/79 data from Montana Department of State Lands
1969, 1970 data from McArthur, George, 1970
Remaining data collected by Hydrometrics.

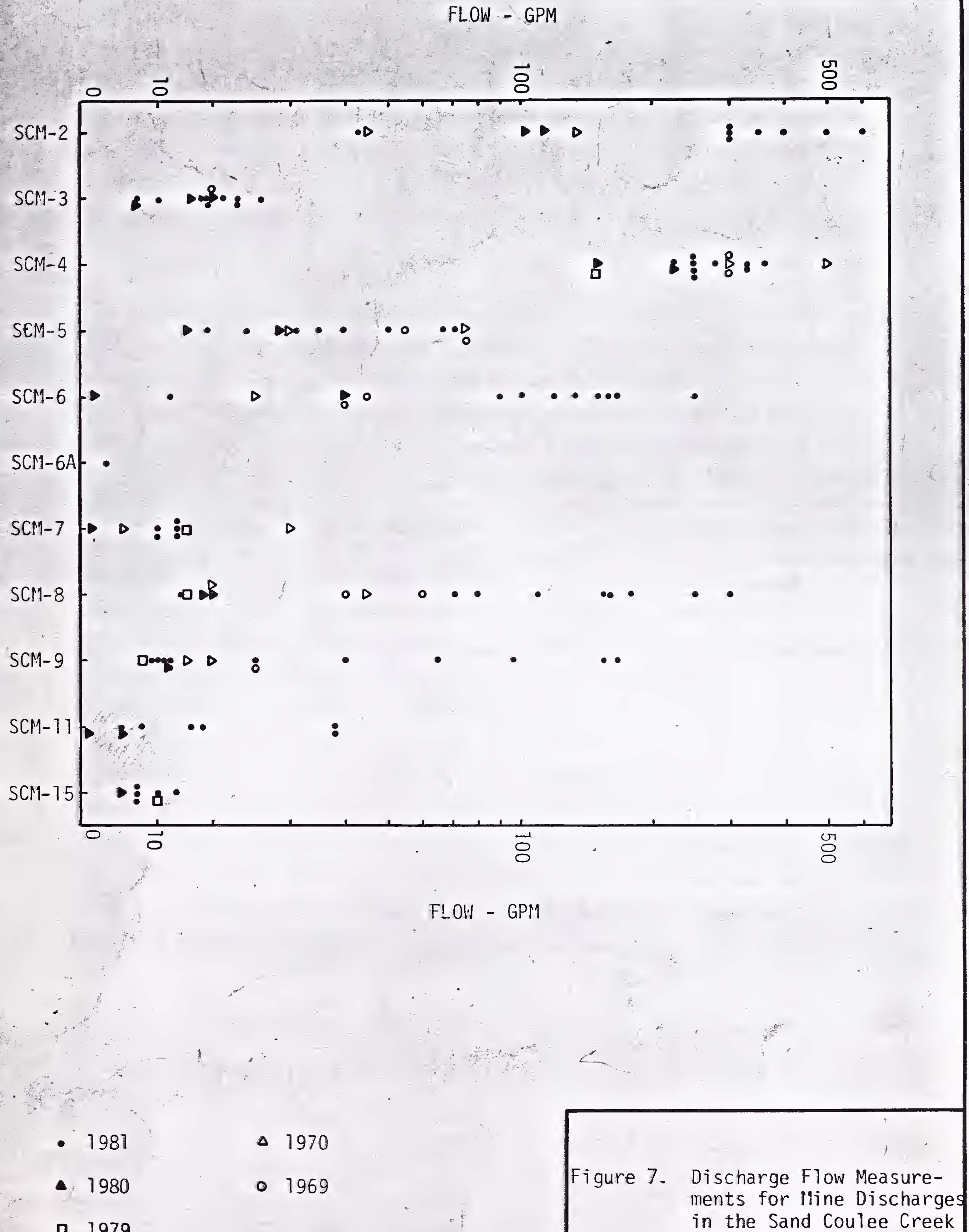


Figure 7. Discharge Flow Measurements for Mine Discharges in the Sand Coulee Creek Drainage for Various Years

sampled in August 1980 is shown in Table 7. As can be seen from Table 7, Mines SCM 2 and SCM 4 contribute 80 percent of the total pollutant load to the stream system. Pollutant load in this example is the product of flow in gpm and specific electrical conductivity in μmhos/cm. This "load factor" gives a comparative indication of water quality impacts from the mines.

The quantity of water discharged from these mines varies widely and it is expected that the relative contribution of pollutants from these mines also is highly variable. Precipitation obviously has a significant influence on discharge from most mines. The wide variability in flow, water quality and pollutant loads creates a most difficult problem to solve.

As shown in Table 7 most mine effluent has a specific electrical conductivity of 3000 to 6000 μmhos/cm with SCM 4, 8, 11 and 15 being significantly lower and SCM 9 significantly higher. With the exception of SCM 15 the mine effluents can be characterized as very acidic, magnesium-calcium sulfate type waters with high concentrations of dissolved solids and metals. Water from SCM 15 is a slightly alkaline, magnesium-calcium-sulfate type water with moderate concentrations of dissolved solids and low concentrations of metals. None of these waters meet federal primary and secondary drinking water standards. Due to high acidity, and high concentrations of total dissolved solids and metals, the mine effluents (except SCM 15) also are unsuitable for irrigation and livestock use. SCM 15 probably would be suitable for both livestock water and irrigation.

TABLE 7. WATER QUALITY CHARACTERISTICS OF COAL MINES IN THE SAND COULEE DRAINAGE

Mine Number and Name	Location	Receiving Stream	Water Quality Sample Taken	Mine Effluent Quality	pH	S.C. @ 25°C (μmhos/cm)	Effluent Discharge (gpm)	Load Factor x 10^4	Relative Load Contribution (percent)
SCM 2	19N04E23ADCB	Sand Coulee	yes	very poor	2.6	4500	114	51	39
SCM 3	19N04E23ADAB	Sand Coulee	yes	very poor	2.4	5100	16	8.2	6
SCM 4	18N04E14ACD	Number Five Coulee	yes	fair	4.7	1200	449	54	41
SCM 5	19N04E14DDCD	Sand Coulee	yes	poor	3.5	3400	15	5.1	4
SCM 6	19N04E13CBD	Sand Coulee	yes	very poor	2.4	5900	1.2	0.7	1
SCM 7	19N05E7ABD	none	yes	poor	2.6	3300	1.4	0.5	<.5
SCM 8	19N05E7CACD	none	yes	poor	2.7	1600	18.7	3.0	2.
SCM 9	18No5E6CDB	Cottonwood Creek	yes	very poor	2.4	6000	12	7.2	5
SCM 11	19N04E13CBA	Sand Coulee	yes	poor	2.8	1700	4.6	.8	1
SCM 15	19N05E7AAAA	none	yes	fair	7.7	1000	4.5	.5	<.5
									100

Notes: Data based on Hydrometrics August 1980 samples and flow measurements
S.C. is specific electrical conductivity
(gpm) is gallons per minute
Loading factor is the product of S.C. and Discharge
See Exhibit 1 for location of mine adits

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM1	SCM1
SAMPLE DATE	09/06/69	07/22/70
PHYSICAL PARAMETERS		
FLOW (GPM)	15	20
WATER TEMPERATURE (C)		10
SPEC. COND. UMHOS/CM LAB	8810	
PH LAB	2.2	2.4
COMMON IONS		
CALCIUM (CA)	19	
ACIDITY AS CACO3	12700	
ALKALINITY AS CACO3	0	
SULFATE (SO4)	13200	
TRACE METALS		
ALUMINUM (AL) TOTAL	670	
IRON (FE) TOTAL	2200	2400
IRON (FE) DISS		450
LOAD FACTOR	13.2	

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8.SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM2	SCM2	SCM2	SCM2	SCM2	SCM2	SCM2	SCM2	SCM2
SAMPLE DATE	08/03/69	09/27/69	10/18/69	03/23/70	07/22/70	08/14/80	09/20/80	01/13/81	04/03/81
PHYSICAL PARAMETERS									
FLOW (GPM)			150	45	135				300
WATER TEMPERATURE (C)	11		10	10	10		10.0		12
SPEC. COND. UMHOS/CM FIELD							5102		5072
SPEC. COND. UMHOS/CM LAB	5540	5180	7990	5320		4500	4568	4800	
PH FIELD							2.62		2.9
PH LAB	2.8	2.6	2.7	2.6	2.7	2.6	2.78	2.6	
TOTAL DISS. SOLIDS MEAS.						5430			
SODIUM ADSORPTION RATIO							0.27		
COMMON IONS									
TOTAL HARDNESS AS CACO3							976.58		
CALCIUM (CA)	58	32	60	67		210	190		
MAGNESIUM (MG)						128	122		
SODIUM (NA)						21	19.4		
POTASSIUM (K)						1	0.3		
ACIDITY AS CACO3		5260	5180	4660		4060	4695	4000	
ALKALINITY AS CACO3	0	0		0					
BICARBONATE (HCO3)						0			
CARBONATE (CO3)						0			
SULFATE (SO4)	5385	5515	5825	5635		5000	4600		
CHLORIDE (CL)						68	3.1		
FLUORIDE (F)						<0.1	4.2		
NUTRIENTS									
AMMONIA (NH4-N)						0.41			
NITRATE (NO3-N)							0.01		
NITRATE + NITRITE AS N						<0.05			
TRACE METALS									
ARSENIC (AS) DISS						0.14	0.0304		
ALUMINUM (AL) TOTAL	407	608	530	84					
ALUMINUM (AL) DISS						379	393		
CADMIUM (CD) DISS						0.060	0.041		
COPPER (CU) DISS						0.14	0.15		
CHROMIUM (CR) DISS						0.27	0.27		
IRON (FE) TOTAL	1270				1260		712		
IRON (FE) DISS					1120	740			
LEAD (PB) DISS						0.05	<0.04		
MANGANESE (MN) DISS						2.08	2.03		
MERCURY (HG) DISS						<0.001	<0.0003		
MOLYBDENUM (MO) DISS						<0.005	0.03		
NICKEL (NI) DISS						4.41	3.96		
SELENIUM (SE) DISS						<0.005	0.0017		
SILVER (AG) DISS						0.010	<0.002		

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM2	SCM2	SCM2	SCM2	SCM2	SCM2	SCM2	SCM2	SCM2
SAMPLE DATE	08/03/69	09/27/69	10/18/69	03/23/70	07/22/70	08/14/80	09/20/80	01/13/81	04/03/81
VANADIUM (V) DISS							0.34		
ZINC (ZN) DISS						20.5	17.6		
OTHER PARAMETERS									
BORON (B)						0.58	0.16		
SILICA (SIO2)						121.9	88.8		
LOAD FACTOR			119.9	23.9					

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM3	SCM3	SCM3	SCM3	SCM3	SCM3
SAMPLE DATE	09/06/69	07/22/70	08/14/80	09/20/80	01/13/81	04/03/81
PHYSICAL PARAMETERS						
FLOW (GPM)	20	20				23
WATER TEMPERATURE (C)		12		9.6		9
SPEC. COND. UMHOS/CM FIELD				5689		2880
SPEC. COND. UMHOS/CM LAB	6480		5100	5292	6000	
PH FIELD				2.46		3.0
PH LAB	2.5	2.6	2.4	2.49	2.4	
TOTAL DISS. SOLIDS MEAS.			6230			
SODIUM ADSORPTION RATIO				0.22		
COMMON IONS						
TOTAL HARDNESS AS CACO3				960.12		
CALCIUM (CA)	25		183	190		
MAGNESIUM (MG)			128	118		
SODIUM (NA)			17	15.9		
POTASSIUM (K)			0	<0.15		
ACIDITY AS CACO3	5720		5000	4560	6350	
ALKALINITY AS CACO3	0					
BICARBONATE (HCO3)			0			
CARBONATE (CO3)			0			
SULFATE (SO4)	8405		5850	5400		
CHLORIDE (CL)			50	2.5		
FLUORIDE (F)			<0.1	4.97		
NUTRIENTS						
AMMONIA (NH4-N)			0.61			
NITRATE (NO3-N)				<0.01		
NITRATE + NITRITE AS N			<0.05			
TRACE METALS						
ARSENIC (AS) DISS			0.17	<0.0001		
ALUMINUM (AL) TOTAL	775					
ALUMINUM (AL) DISS			470	481		
CADMIUM (CD) DISS			0.072	0.11		
COPPER (CU) DISS			0.22	0.23		
CHROMIUM (CR) DISS			0.27	0.28		
IRON (FE) TOTAL		1790		502		
IRON (FE) DISS		1320	720			
LEAD (PB) DISS			0.07	<0.04		
MANGANESE (MN) DISS			2.41	2.54		
MERCURY (HG) DISS			<0.001	<0.00003		
MOLYBDENUM (MO) DISS			0.005	0.03		
NICKEL (NI) DISS			5.22	4.6		
SELENIUM (SE) DISS			0.005	0.0014		
SILVER (AG) DISS			<0.005	<0.002		

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM3	SCM3	SCM3	SCM3	SCM3	SCM3
SAMPLE DATE	09/06/69	07/22/70	08/14/80	09/20/80	01/13/81	04/03/81
VANADIUM (V) DISS				0.15		
ZINC (ZN) DISS			21.8	19.5		
OTHER PARAMETERS						
BORON (B)			0.58	0.19		
SILICA (SIO2)			147.6	104.0		
LOAD FACTOR	13.0					

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM4	SCM4	SCM4	SCM4	SCM4	SCM4	SCM4	SCM4	SCM4	SCM4
SAMPLE DATE	08/03/69	09/06/69	03/23/70	07/22/70	09/27/70	10/13/70	08/14/80	09/20/80	03/03/81	04/03/81
PHYSICAL PARAMETERS										
FLOW (GPM)		300	300	500		300				250
WATER TEMPERATURE (C)	10		8	9		10		9.2	7.9	10
SPEC. COND. UMHOS/CM FIELD								1122	1038	946
SPEC. COND. UMHOS/CM LAB	1393	1881	1455		1820	2060	1200	1209	1984	
PH FIELD								5.41	5.39	5.5
PH LAB	3.6	2.8	3.1	3.5	2.8	2.9	4.7	3.32	3.62	
TOTAL DISS. SOLIDS MEAS.							8.26			
SODIUM ADSORPTION RATIO								0.30	0.21	
COMMON IONS										
TOTAL HARDNESS AS CACO3								473.36	253.75	
CALCIUM (CA)	126	164	48		159	155	120	121	64.7	
MAGNESIUM (MG)							40	41.6	22.4	
SODIUM (NA)							15	14.9	7.7	
POTASSIUM (K)							6	5.8	4.2	
ACIDITY AS CACO3		449	174		390	303	263	108		
ALKALINITY AS CACO3	0	0	0		0					
BICARBONATE (HCO3)							0			
CARBONATE (CO3)							0			
SULFATE (SO4)	791	917	625		895	162	566	548	632	
CHLORIDE (CL)							79	3.5	4.8	
FLUORIDE (F)							1.4	1.05	1.23	
NUTRIENTS										
AMMONIA (NH4-N)							0.33			
NITRATE (NO3-N)								<0.02	0.11	
NITRATE + NITRITE AS N							<0.05			
TRACE METALS										
ARSENIC (AS) DISS							<0.005	0.0019	0.0062	
ALUMINUM (AL) TOTAL	16	29	3		26					
ALUMINUM (AL) DISS							2.9	3.04	1.16	
CADMIUM (CD) DISS							0.002	0.005	0.029	
COPPER (CU) DISS							0.01	0.013	0.042	
CHROMIUM (CR) DISS							<0.02	0.004	0.040	
IRON (FE) TOTAL	127			200				62.5	29.1	
IRON (FE) DISS				180			60			
LEAD (PB) DISS							<0.01	<0.04	0.05	
MANGANESE (MN) DISS							0.46	0.39	0.221	
MERCURY (HG) DISS							<0.001	0.00004		
MOLYBDENUM (MO) DISS							<0.005	<0.02	0.27	
NICKEL (NI) DISS							0.38	.30	0.24	
SELENIUM (SE) DISS							<0.005	0.0003		
SILVER (AG) DISS							<0.005	<0.002	0.057	

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM4	SCM4	SCM4	SCM4	SCM4	SCM4	SCM4	SCM4	SCM4	SCM4
SAMPLE DATE	08/03/69	09/06/69	03/23/70	07/22/70	09/27/70	10/13/70	08/14/80	09/20/80	03/03/81	04/03/81
VANADIUM (V) DISS								0.009	0.055	
ZINC (ZN) DISS							1.39	1.23	0.600	
OTHER PARAMETERS										
BORON (B)							<0.10	0.06	0.14	
SILICA (SIO2)							29.9	20.6	10.6	
LOAD FACTOR		56.4	43.7			61.8				

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM5	SCM5	SCM5	SCM5	SCM5	SCM5	SCM5	SCM5	SCM5	SCM5
SAMPLE DATE	09/06/69	09/27/69	03/23/70	07/22/70	10/18/70	08/14/80	09/20/80	01/13/81	03/03/81	04/20/81
PHYSICAL PARAMETERS										
FLOW (GPM)	55		30	75	75					50
WATER TEMPERATURE (C)			8	20	4		14		11.0	13
SPEC. COND. UMHOS/CM FIELD							3329		4105	3248
SPEC. COND. UMHOS/CM LAB	3600	3970	3400		5260	3400	3638	3500	3573	
PH FIELD							3.84		3.98	4.5
PH LAB	2.6	2.6	2.7	4.0	2.7	3.5	3.04	3.0	3.0	
TOTAL DISS. SOLIDS MEAS.						3740				
SODIUM ADSORPTION RATIO							0.33		0.31	
COMMON IONS										
TOTAL HARDNESS AS CACO3							974.42		990.0	
CALCIUM (CA)	113	99	126		125	180	171		169	
MAGNESIUM (MG)						135	133		138	
SODIUM (NA)						26	23.5		22.6	
POTASSIUM (K)						5	4.4		4.7	
ACIDITY AS CACO3	2130	2265	1780		2054	2275	2077	2500	2315	
ALKALINITY AS CACO3	0	0	0							
BICARBONATE (HCO3)						0			0	
CARBONATE (CO3)						0			0	
SULFATE (SO4)	2900	3020	2595		2855	3330	3560		3222	
CHLORIDE (CL)						60	4.9		5.3	
FLUORIDE (F)						<0.1	3.31		3.02	
NUTRIENTS										
AMMONIA (NH4-N)						1.4				
NITRATE (NO3-N)							<0.02		0.85	
NITRATE + NITRITE AS N						<0.05				
TRACE METALS										
ARSENIC (AS) DISS						0.050	0.0405		0.039	
ALUMINUM (AL) TOTAL	272	238	1780		298					
ALUMINUM (AL) DISS						224	243		456	
CADMIUM (CD) DISS						0.013	0.027		0.027	
COPPER (CU) DISS						0.02	0.041		0.026	
CHROMIUM (CR) DISS						0.09	0.064		0.067	
IRON (FE) TOTAL				400			436		466	
IRON (FE) DISS				350		460				
LEAD (PB) DISS						0.03	<0.04		2.12	
MANGANESE (MN) DISS						1.69	1.63		1.59	
MERCURY (HG) DISS						<0.001	<0.00003			
MOLYBDENUM (MO) DISS						0.010	0.03		0.19	
NICKEL (NI) DISS						2.34	2.10		2.12	
SELENIUM (SE) DISS						<0.005	0.0005		0.0004	
SILVER (AG) DISS						<0.005	<0.002		0.023	

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM5	SCM5	SCM5	SCM5	SCM5	SCM5	SCM5	SCM5	SCM5	SCM5
SAMPLE DATE	09/06/69	09/27/69	03/23/70	07/22/70	10/18/70	08/14/80	09/20/80	01/13/81	03/03/81	04/20/81
VANADIUM (V) DISS							0.14		0.168	
ZINC (ZN) DISS						8.73	8.34		8.19	
OTHER PARAMETERS										
BORON (B)						0.42	0.07		0.24	
SILICA (SIO2)						81.3	54.5		51.2	
LOAD FACTOR	19.8		10.2		39.4					

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8.SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM6	SCM6	SCM6	SCM6	SCM6	SCM6	SCM6	SCM6	SCM6
SAMPLE DATE	08/03/69	09/06/69	09/27/69	10/18/69	07/22/70	08/14/80	09/20/80	01/13/81	04/20/81
PHYSICAL PARAMETERS									
FLOW (GPM)		45		40	25				120
WATER TEMPERATURE (C)	19			4	20		11.9		13
SPEC. COND. UMHOS/CM FIELD							6362		8420
SPEC. COND. UMHOS/CM LAB	2813	5730	5540	8634		5900	6238	6000	
PH FIELD							2.38		2.3
PH LAB	3.7	2.5	2.5	2.3	2.6	2.4	2.55	2.4	
TOTAL DISS. SOLIDS MEAS.						7640			
SODIUM ADSORPTION RATIO							0.23		
COMMON IONS									
TOTAL HARDNESS AS CACO3							1210.32		
CALCIUM (CA)	93	32	23	46		217	188		
MAGNESIUM (MG)						159	180		
SODIUM (NA)						20	18.2		
POTASSIUM (K)						1	0.6		
ACIDITY AS CACO3		6420	5930	5780		4770	5195	6300	
ALKALINITY AS CACO3	0	0	0						
BICARBONATE (HCO3)						0	0		
CARBONATE (CO3)						0	0		
SULFATE (SO4)	2445	7135	6165	6275		7180	7940		
CHLORIDE (CL)						65	4.1		
FLUORIDE (F)						<0.1	7.2		
NUTRIENTS									
AMMONIA (NH4-N)						0.36			
NITRATE (NO3-N)							0.02		
NITRATE + NITRITE AS N						<0.05			
TRACE METALS									
ARSENIC (AS) DISS						0.24	0.0796		
ALUMINUM (AL) TOTAL	184	602	625	523					
ALUMINUM (AL) DISS						545	588		
CADMIUM (CD) DISS						0.080	0.034		
COPPER (CU) DISS						0.46	0.37		
CHROMIUM (CR) DISS						0.25	0.27		
IRON (FE) TOTAL	700				1340		1004		
IRON (FE) DISS					940	1020			
LEAD (PB) DISS						0.07	<0.04		
MANGANESE (MN) DISS						4.69	4.45		
MERCURY (HG) DISS						<0.001	0.00004		
MOLYBDENUM (MO) DISS						0.008	0.02		
NICKEL (NI) DISS						3.86	3.58		
SELENIUM (SE) DISS						0.005	0.0021		
SILVER (AG) DISS						<0.005	0.007		

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM6	SCM6	SCM6	SCM6	SCM6	SCM6	SCM6	SCM6	SCM6
SAMPLE DATE	08/03/69	09/06/69	09/27/69	10/18/69	07/22/70	08/14/80	09/20/80	01/13/81	04/20/81
VANADIUM (V) DISS							0.25		
ZINC (ZN) DISS						13.1	13.6		
OTHER PARAMETERS									
BORON (B)						0.72	0.18		
SILICA (SIO2)						171.2	128.0		
LOAD FACTOR		25.8		34.5					

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM7	SCM7	SCM7	SCM7
SAMPLE DATE	03/23/70	07/22/70	08/14/80	04/20/81
PHYSICAL PARAMETERS				
FLOW (GPM)	5	30		15
WATER TEMPERATURE (C)	8	10		12
SPEC. COND. UMHOS/CM FIELD				3667
SPEC. COND. UMHOS/CM LAB	2820		3300	
PH FIELD				2.3
PH LAB	2.4	2.5	2.6	
TOTAL DISS. SOLIDS MEAS.			3550	
COMMON IONS				
CALCIUM (CA)			14	
MAGNESIUM (MG)			137	
SODIUM (NA)			28	
POTASSIUM (K)			1	
ACIDITY AS CACO3	940		1970	
BICARBONATE (HCO3)			0	
CARBONATE (CO3)			0	
SULFATE (SO4)	2620		3010	
CHLORIDE (CL)			14	
FLUORIDE (F)			<0.10	
NUTRIENTS				
AMMONIA (NH4-N)			0.33	
NITRATE + NITRITE AS N			0.09	
TRACE METALS				
ARSENIC (AS) DISS			0.031	
ALUMINUM (AL) TOTAL	130			
ALUMINUM (AL) DISS			134	
CADMIUM (CD) DISS			0.073	
COPPER (CU) DISS			0.17	
CHROMIUM (CR) DISS			0.05	
IRON (FE) TOTAL	105	120		
IRON (FE) DISS		95	310	
LEAD (PB) DISS			<0.01	
MANGANESE (MN) DISS			1.65	
MERCURY (HG) DISS			<0.001	
MOLYBDENUM (MO) DISS			<0.005	
NICKEL (NI) DISS			2.27	
SELENIUM (SE) DISS			<0.005	
SILVER (AG) DISS			<0.005	
ZINC (ZN) DISS			8.56	
OTHER PARAMETERS				
BORON (B)			0.32	
SILICA (SIO2)			102.7	
LOAD FACTOR	1.4			

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM8	SCM8	SCM8	SCM8	SCM8	SCM8	SCM8
SAMPLE DATE	09/06/69	03/23/70	07/22/70	10/18/70	08/14/80	09/21/80	04/20/81
PHYSICAL PARAMETERS							
FLOW (GPM)	60	20	45	40			155
WATER TEMPERATURE (C)		9	10	10		10.5	12
SPEC. COND. UMHOS/CM FIELD						1862	2382
SPEC. COND. UMHOS/CM LAB	2380	2450		2590	1600	1839	
PH FIELD						2.88	3.0
PH LAB	2.7	2.8	2.9	2.4	2.7	2.93	
TOTAL DISS. SOLIDS MEAS.					1310		
SODIUM ADSORPTION RATIO						0.42	
COMMON IONS							
TOTAL HARDNESS AS CACO3						540.93	
CALCIUM (CA)	118	140		122	85	93.5	
MAGNESIUM (MG)					72	74.7	
SODIUM (NA)					24	22.3	
POTASSIUM (K)					3	2.4	
ACIDITY AS CACO3	870	730		780	405	432	
ALKALINITY AS CACO3	0	0					
BICARBONATE (HCO3)					0	0	
CARBONATE (CO3)					0	0	
SULFATE (SO4)	1450	2430		1380	1050	980	
CHLORIDE (CL)					10	6.3	
FLUORIDE (F)					2.5	0.04	
NUTRIENTS							
AMMONIA (NH4-N)					0.17		
NITRATE (NO3-N)							
NITRATE + NITRITE AS N					<0.05		
TRACE METALS							
ARSENIC (AS) DISS					0.017	0.0019	
ALUMINUM (AL) TOTAL	90	90		93			
ALUMINUM (AL) DISS					35	47.5	
CADMIUM (CD) DISS					0.012	0.018	
COPPER (CU) DISS					0.03	0.030	
CHROMIUM (CR) DISS					<0.02	0.005	
IRON (FE) TOTAL			54			12.4	
IRON (FE) DISS			2.6		12.4		
LEAD (PB) DISS					0.01	<0.04	
MANGANESE (MN) DISS					0.90	0.89	
MERCURY (HG) DISS					<0.001	<0.0003	
MOLYBDENUM (MO) DISS					<0.005	<0.02	
NICKEL (NI) DISS					0.58	0.54	
SELENIUM (SE) DISS					<0.005	0.0004	
SILVER (AG) DISS					<0.005	<0.002	

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM8	SCM8	SCM8	SCM8	SCM8	SCM8	SCM8
SAMPLE DATE	09/06/69	03/23/70	07/22/70	10/18/70	08/14/80	09/21/80	04/20/81
VANADIUM (V) DISS						0.006	
ZINC (ZN) DISS					1.69	1.66	
OTHER PARAMETERS							
BORON (B)					0.16	0.12	
SILICA (SIO2)					100.5	68.5	
LOAD FACTOR	14.3	4.9		10.4			

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM9	SCM9	SCM9	SCM9	SCM9	SCM9	SCM9	SCM9
SAMPLE DATE	08/03/69	09/06/69	03/23/70	07/27/70	08/14/80	09/21/80	03/03/81	04/20/81
PHYSICAL PARAMETERS								
FLOW (GPM)		25	15	20				12
WATER TEMPERATURE (C)	23		5	10		10.2	8.6	10
SPEC. COND. UMHOS/CM FIELD						6747	6826	6356
SPEC. COND. UMHOS/CM LAB	6520	6170	6710		6000	6287	6251	
PH FIELD						2.45	2.53	2.8
PH LAB	2.7	2.4	2.5	2.7	2.4	2.9	2.82	
TOTAL DISS. SOLIDS MEAS.					6540			
SODIUM ADSORPTION RATIO						0.17	0.16	
COMMON IONS								
TOTAL HARDNESS AS CACO3						1474.75	1536.9	
CALCIUM (CA)	56	57	56		403	345	360	
MAGNESIUM (MG)					144	149	155	
SODIUM (NA)					16	14.7	14.1	
POTASSIUM (K)					1	0.8	2.6	
ACIDITY AS CACO3		6580	6950		5300	5294	5431	
ALKALINITY AS CACO3	0	0	0					
BICARBONATE (HCO3)					0			
CARBONATE (CO3)					0			
SULFATE (SO4)	7360	7735	8250		5910	6480	6906	
CHLORIDE (CL)					56	17.4	1.9	
FLUORIDE (F)					<0.1	0.86	7.46	
NUTRIENTS								
AMMONIA (NH4-N)					1.4			
NITRATE (NO3-N)						0.02	0.18	
NITRATE + NITRITE AS N					<0.05			
TRACE METALS								
ARSENIC (AS) DISS					0.22	0.0028		
ALUMINUM (AL) TOTAL	449	564	110					
ALUMINUM (AL) DISS					444	479	500	
CADMIUM (CD) DISS					0.082	0.15	0.112	
COPPER (CU) DISS					0.12	0.12	0.154	
CHROMIUM (CR) DISS					0.12	0.11	0.144	
IRON (FE) TOTAL	1918			1460		1057	1065	
IRON (FE) DISS	1830			1220	1060			
LEAD (PB) DISS					0.08	<0.04	<0.04	
MANGANESE (MN) DISS					2.61	2.46	2.56	
MERCURY (HG) DISS					<0.001	<0.00003		
MOLYBDENUM (MO) DISS					0.008	0.05	1.42	
NICKEL (NI) DISS					15.1	12.4	12.8	
SELENIUM (SE) DISS					0.009	0.001	0.8	
SILVER (AG) DISS					<0.005	0.017	0.092	

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM9	SCM9	SCM9	SCM9	SCM9	SCM9	SCM9	SCM9
SAMPLE DATE	08/03/69	09/06/69	03/23/70	07/27/70	08/14/80	09/21/80	03/03/81	04/20/81
VANADIUM (V) DISS						0.21	0.033	
ZINC (ZN) DISS					60.4	62.9	4.85	
OTHER PARAMETERS								
BORON (B)					0.68	0.20	0.33	
SILICA (SIO2)					139.1	113.0	106.0	
LOAD FACTOR		15.4	10.1					

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM11	SCM11	SCM15	SCM15
SAMPLE DATE	08/14/80	09/20/80	08/14/80	04/20/81
PHYSICAL PARAMETERS				
FLOW (GPM)	4.6		4.5	6-8
WATER TEMPERATURE (C)		10.4		10
SPEC. COND. UMHOS/CM FIELD		1701		1009
SPEC. COND. UMHOS/CM LAB	1800	1808	1000	
PH FIELD		3.02		6.3
PH LAB	2.8	2.97	7.7	
TOTAL DISS. SOLIDS MEAS.	1360		835	
SODIUM ADSORPTION RATIO		0.35		
COMMON IONS				
TOTAL HARDNESS AS CACO3		520.31		
CALCIUM (CA)	54	62.0	93	
MAGNESIUM (MG)	88	88.8	102	
SODIUM (NA)	20	18.2	20	
POTASSIUM (K)	3	2.4	5	
ACIDITY AS CACO3	540	561		
BICARBONATE (HCO3)	0		231	
CARBONATE (CO3)	0		0	
SULFATE (SO4)	1120	1060	490	
CHLORIDE (CL)	13	7.6	11	
FLUORIDE (F)	1.3	2.40	1.6	
NUTRIENTS				
AMMONIA (NH4-N)	0.62		<0.10	
NITRATE (NO3-N)		0.02		
NITRATE + NITRITE AS N	<0.05		1.2	
TRACE METALS				
ARSENIC (AS) DISS	0.032	0.00169	<0.005	
ALUMINUM (AL) DISS	38	60.6	<0.1	
CADMIUM (CD) DISS	0.005	0.010	<0.001	
COPPER (CU) DISS	0.01	0.009	<0.01	
CHROMIUM (CR) DISS	<0.02	0.011	<0.02	
IRON (FE) TOTAL		74.1		
IRON (FE) DISS	70		0.05	
LEAD (PB) DISS	0.01	<0.04	<0.01	
MANGANESE (MN) DISS	1.14	1.07	0.04	
MERCURY (HG) DISS	<0.001	0.00012	<0.001	
MOLYBDENUM (MO) DISS	<0.005	<0.02	<0.005	
NICKEL (NI) DISS	0.52	0.42	0.05	
SELENIUM (SE) DISS	<0.005	0.0003	0.016	
SILVER (AG) DISS	<0.005	<0.002	<0.005	
VANADIUM (V) DISS		0.027		
ZINC (ZN) DISS	0.97	0.87	0.04	

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 8. SUMMARY OF WATER QUALITY SAMPLING - Sand Coulee Mine Discharge

SAMPLING SITE	SCM11	SCM11	SCM15	SCM15
SAMPLE DATE	08/14/80	09/20/80	08/14/80	04/20/81
OTHER PARAMETERS				
BORON (B)	0.21	0.17	0.11	
SILICA (SIO2)	83.4	50.5	10.7	
LOAD FACTOR	0.8		0.4	

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

Groundwater

There have been no detailed studies of groundwater resources in the Sand Coulee Creek drainage. Fisher (1909) examined the general hydrogeology of a very large area in south central Montana including the Sand Coulee Creek drainage. His report included a general discussion of hydrogeology in the Sand Coulee Creek drainage. Goers (1968) described geology of the Stockett-Smith River area of Montana and provided data on wells and springs and discussed groundwater in the Stockett-Sand Coulee area. Walker (1974) discussed the Kootenai Formation south of Great Falls and described some hydrogeological relationships in the Kootenai Formation. McArthur (1970) included a general discussion of groundwater resources and geology of the Sand Coulee Creek drainage.

In the Sand Coulee Creek drainage the occurrence, movement, quantity and quality of groundwater is closely related to geology of the area. Formations of particular importance to groundwater resources are the Mission Canyon Formation of Mississippian geological age, the Swift and Morrison Formations of Jurassic age, and the Kootenai Formation of Cretaceous age. Other geological deposits of importance in groundwater includes unconsolidated alluvium of Quaternary age along major drainages and Quaternary alluvium in an ancient channel of the Missouri River present along the north edge of the Sand Coulee Creek drainage.

Wells in the Sand Coulee Creek drainage obtain groundwater from the Mission Canyon, Swift, Morrison and Kootenai Formations and from unconsolidated alluvium deposits along stream channels. Springs in the area predominantly are associated with the Kootenai Formation. A generalized geological cross-section of Sand Coulee Creek drainage showing stratigraphy and geological relationships is shown in Figure 3.

The oldest strata exposed in the Sand Coulee Creek drainage are limestones and dolomites of the Mission Canyon Formation which are exposed in the central part of the drainage (Exhibit 2). The upper

few hundred feet of this formation contains porous and cavernous zones that can store and transmit considerable groundwater. The unaltered sections of the Mission Canyon Formation have low porosity and permeability. Fractures and solution cavities create the high permeabilities often found in the upper sections of this formation. The Mission Canyon Formation outcrops over a broad area in the Little Belt Mountains and dips gently northward. Groundwater movement in the Mission Canyon probably also is northward. Wells in the Mission Canyon Formation near Tracy draw and expell air suggesting channelways that allow air passage. These wells also are reported to yield considerable water (Goers, 1968).

Overlying the Mission Canyon Formation is 40 to 60 feet of sandstone of the Swift Formation. This unit generally is permeable and is jointed and fractured in some outcrops. Few wells are completed in the Swift. Groundwater recharge to the Swift Formation is limited by impermeable shales of the overlying Morrison Formation and up-dip truncation along the Little Belt Mountains (Goers, 1968).

The Morrison Formation overlies the Swift Formation and outcrops along all major drainages in the area. The lower portion of the Morrison Formation contains some sandstone lenses and layers that are tapped by several wells in the Sand Coulee Creek drainage. This formation contains thick, impervious shale layers that limit downward movement of groundwater.

The most important groundwater bearing unit in the Sand Coulee drainage is the Kootenai Formation that, where unaffected by erosion, is about 325 to 450 feet thick. The Kootenai is present at the ground surface in much of the drainage and the formation is a widely used source of groundwater in the area. The Kootenai Formation is fractured and jointed and can store and transmit small to moderate quantities of groundwater (Goers, 1968). The basal conglomerate unit of the Kootenai is a good aquifer and most wells completed in the basal unit yield sufficient water for stock and domestic purposes.

Unconsolidated alluvium is present along all major drainages in the area. This alluvium ranges in thickness from a few feet to over 150 feet (McArthur, 1970). The alluvium is composed of layers and mixtures of sand, gravel, silt and clay. Just north of the community of Sand Coulee the alluvium broadens in width to as much as a mile and is probably underlain by silt, clay and sand deposited by an ancient channel of the Missouri River. Alluvium along Sand Coulee Creek supplies some water to wells but, due to groundwater pollution, the alluvium is not extensively used as a source of groundwater.

Another geological unit that is not utilized by wells is the coal seam in the upper portion of the Morrison Formation. During underground coal mining, the coal seam often flowed considerable water from drill holes for an extended period of time (John Mittal, pers. comm., August 1980).

Groundwater Useage

Groundwater is used in the Sand Coulee drainage for domestic, stock, household, irrigation and public water supply purposes. Most of the community of Stockett is supplied by an infiltration gallery, supplied mostly by springs located east of town. The community of Sand Coulee is supplied by two deep wells and the community of Tracy also is supplied by deep wells. To obtain information on groundwater resources, an inventory was made of wells in the area. This inventory utilized information from files of the Montana Department of Natural Resources and Conservation, data obtained by Goers (1968) in his study of geology of the Stockett area and from on-the-ground inventories in the drainage. Results of the well inventory are tabulated in Table 9 and results of an inventory of springs in the drainage are tabulated in Table 10. Locations of all wells and springs in the drainage are shown on Exhibit 1. Nearly all water supplies in the drainage are derived from groundwater and many are from springs present along the valley edges and from wells drilled into strata beneath the alluvium in Sand Coulee Creek and its tributaries.

TABLE 9. WATER WELLS IN THE SAND COULEE CREEK DRAINAGE

Location T R Sec Tract	SWL (ft.)	Date Measured	Aquifer	Use
17N4E2BD	30	7-6-65	Lower Kootenai Formation	D
17N4E5DC	30	6-30-65	Lower Kootenai Formation	S
17N5E6BD	50	7-10-65	Lower Kootenai Formation	D.S.I.
17N5E6CB	105	7-10-65	Lower Kootenai Formation	D.S.I.
17N5E6BA	20	7-10-65	Lower Kootenai Formation	D
18N4E9CA	Flows	7-23-65	Kootenai Formation	D.S.I.
18N4E10BD	10	7-5-65	Kootenai Formation	D
18N4E10AC	15	7-22-65	Swift Formation	D.I.
18N4E10AA	Dry	7-5-65	Madison Group	None
18N4E10AA	6.0	7-5-65	Swift Formation	None
18N4E12BB	9.8	7-2-65	Kootenai Formation	D.S.
18N4E14CA	20	6-29-65	Swift Formation	D.S.
18N4E16DC	3.5	7-2-65	Kootenai Formation	D.S.
18N4E25AA	Flows	7-8-65	Lower Kootenai Formation	D
18N4E29DD	5.9	7-2-65	Kootenai Formation	D.S.
18N4E34BB	30	7-2-65	Kootenai Formation	None
18N4E35BB	221	7-2-65	Lower Kootenai Formation	D.S.
18N4E35BB	20	7-2-65	Kootenai Formation	D
18N5E6BB	10	7-6-65	Alluvium	D
18N5E6BC	28	7-13-65	Swift Formation-Alluvium	D.S.
18N5E7DC	Dry	7-13-65	Lower Kootenai Formation	None
18N5E8AC	16.8	7-14-65	Swift Formation	S.I.
18N5E16BB	7.5		Alluvium	D
18N5E19DA	8	7-13-65	Kootenai Formation	D.S.I.
18N5E20CD	3.7	7-13-65	Kootenai Formation	S.I.
18N5E28CC	44	7-13-65	Kootenai Formation	D.S.I.
18N5E29CD	13.4	7-10-65	Kootenai Formation	D.S.
18N5E29BB	3.9	7-13-65	Alluvium-Kootenai	D.I.
18N5E31BC	75	7-8-65	Kootenai Formation	D
18N5E32AA	20	7-14-65	Kootenai Formation	D.S.

TABLE 9. - continued

Location T R Sec Tract	SWL (ft.)	Date Measured	Aquifer	Use
19N4E3BC	15	8-29-65	Alluvium	D.I.
19N4E5AC	20	8-1-65	Lower Kootenai Formation	D
19N4E9CA	100	7-31-65	Madison Group	D
19N4E10BC	Flows	7-23-65	Kootenai Formation	None
19N4E13A	167.5		Lower Morrison Upper Madison	D.I.
19N4E13A	172.5		Lower Morrison Upper Madison	D.I.
19N4E13A	162.5		Lower Morrison Upper Madison	D.I.
19N4E13BA	134	7-22-65	Basal Kootenai	D.I.
19N4E13CB	28			
19N4E14BD		7-23-65	Lower Kootenai Formation	D.S.I.
19N4E14D				D
19N4E15BC	55	7-23-65	Lower Kootenai Formation	D.I.
19N4E21DC	11	8-24-65	Lower Kootenai Formation	D.S.
19N4E23BB	167.5		Basal Kootenai Formation	D
19N4E23BB	0.2	7-23-65	Kootenai Formation	D.S.I.
19N4E23B	512.5		Madison Formation	D.I.
19N4E23CC	0.9	7-22-65	Kootenai Formation	S
19N4E23CD	5.4	7-23-65	Lower Kootenai Formation	D.S.
19N4E23DD	10.8	7-23-65	Kootenai Formation	None
19N4E28BC	1.3	8-28-65	Alluvium	S.I.
19N4E28CB		8-28-65	Kootenai Formation	D
19N4E33CA	180	7-22-65	Basal Kootenai Formation	D
19N4E34BC	16	7-22-65	Lower Kootenai Formation	D
19N4E36DC	12	7-6-65	Alluvium	D
19N4E36DD	30.9	7-13-65	Swift Formation	None
19N5E6BD	73.5		Alluvium	D.I.
19N5E7B	162.5		Basal Madison Kootenai	D.I.
19N5E7CB	100	7-23-65	Madison	D.S.I.

TABLE 9. - continued

Location T R Sec Tract	SWL (ft.)	Date Measured	Aquifer	Use
19N5E18BB	165	7-22-65	Madison Group	D.S.I.
19N5E18A	165			
19N5E18DB	160	7-22-65	Madison Group	D
19N5E19BD	187	7-22-65	Madison Group	D
19N5E29DD	6	7-5-65	Basal Kootenai Formation	None
20N4E32AC	25	8-29-65	Alluvium	D
20N4E33BB	12	8-29-65	Alluvium-Swift	D.S.I.
20N4E33BB	14	8-29-65	Madison Group Alluvium	D.I.
20N4E33BD	Dry	8-29-65	Alluvium	None
20N4E33DB	20	8-29-65	Lower Kootenai	D.S.I.
20N4E36AD		9-3-65	Kootenai-Swift	D.S.
20N4E36BA	23	9-3-65	Alluvium	D.S.I.
20N4E36BA	23	9-3-65	Alluvium	D.S.I.

D - Domestic

S - Stock

I - Irrigation

TABLE 10. SPRINGS IN THE SAND COULEE CREEK DRAINAGE

Location T R Sec Tract	Estimated Flow (gpm)	Aquifer
18N4E9DC		
18N4E14AC		
18N4E15D*	3	
18N4E21C*	25	Kootenai Formation
18N4E22C*	20	Lower Kootenai Formation
18N4E28CC		
18N4E29D*	3	Kootenai Formation
18N5E6CC		
18N5E8CC		
18N5E10BD		
18N5E20AD		
18N5E27CD		
19N4E2B*	15	Basal Kootenai Formation
19N4E3B*	1	Basal Kootenai Formation
19N4E12CB		
19N4E14DC		
19N4E21A*	50	Kootenai Formation
19N5E3CC		

* Source: Goers (1968), all others from USGS Topographic Map

Groundwater Quality

Water quality data were obtained for selected wells and springs in the Sand Coulee Creek drainage (Table 11). The springs are associated with the Kootenai Formation. Water from springs (SF 8, SF 16, SF 20, and Stockett Spring) is of good quality and is a very hard, alkaline, magnesium-calcium-bicarbonite type with low to moderate concentrations of dissolved solids and metals. The wells (Sand Coulee well and Tracy well) probably obtain water from the Mission Canyon Formation. This water also is very hard, alkaline, magnesium-calcium-bicarbonate type with low concentrations of metals and low to moderate concentrations of dissolved solids. Where not influenced by acid drainage, groundwater in the drainage is fair to good quality and is suitable for livestock, domestic, and public water supply purposes.

Recharge and Discharge

Groundwater recharge and discharge relationships have not been studied in detail in the Sand Coulee Creek drainage. The flow of acid water from most discharging mines in the drainage (Figure 4) responds rapidly to precipitation (Figure 5). This clearly shows that infiltration of precipitation into the Kootenai Formation provides significant recharge to groundwater systems. The coal seam underlies the Kootenai and obviously receives vertical recharge from the Kootenai.

The Kootenai Formation is at or near the ground surface in much of the drainage. It is the most important geological unit in the drainage and furnishes water to many wells and springs. To better understand the hydrogeology of this unit, a map was prepared showing the potentiometric surface in the Kootenai (Exhibit 3). This map shows lines of equal hydraulic head in the groundwater system. Flow of groundwater is essentially perpendicular to the equal potential lines.

As shown on Exhibit 3, the general flow of groundwater in the Kootenai Formation is northward. The map also shows that ridges between

TABLE 11. SUMMARY OF WATER QUALITY SAMPLING - SAND COULEE Groundwater

SAMPLING SITE	TRACY PUB SPLY	S COUL PUB SPLY	STOCKETT PUB SPLY	SF8	SF16	SF20
SAMPLE DATE	05/18/79	05/18/79	06/05/73	08/20/80	08/20/80	08/20/80
PHYSICAL PARAMETERS						
SPEC. COND. UMHOS/CM LAB	665.0	875.0	640.0	750	770	350
PH LAB	7.85	7.59	7.499	7.4	8.0	7.3
TOTAL DISS. SOLIDS MEAS.	530.9	735.2	574.8	466	506	204
SODIUM ADSORPTION RATIO	0.3	0.4	0.3			
COMMON IONS						
TOTAL HARDNESS AS CACO3	347	464	350			
CALCIUM (CA)	86.7	61.5	83	59	61	38
MAGNESIUM (MG)	31.8	75.3	35	74	79	25
SODIUM (NA)	13.6	20.6	11	16	19	6
POTASSIUM (K)	2.6	4.3		3	8	3
ALKALINITY AS CACO3	203	386	292			
BICARBONATE (HCO3)	247.7	470.9	356	429	515	239
CARBONATE (CO3)	0	0	0	0	0	0
HYDROXIDE (OH)			0			
SULFATE (SO4)	138	90.7	66	84	67	11
CHLORIDE (CL)	8.1	10.2	3.1	16	15	1
FLUORIDE (F)	0.64	1.40	0.45	0.9	0.9	0.2
NUTRIENTS						
AMMONIA (NH4-N)				0.12		1.4
NITRATE (NO3-N)			21			
NITRATE + NITRITE AS N	1.80	0.25		5.0	2.1	0.86
ORTHO-PHOSPHATE (PO4-P)			<0.01			
TRACE METALS						
ARSENIC (AS) TOTAL	0.001	<0.001	<0.01			
ARSENIC (AS) DISS				<0.005		<0.005
ALUMINUM (AL) DISS				<0.1		<0.1
CADMIUM (CD) TOTAL	<0.001	<0.001	<0.01			
CADMIUM (CD) DISS				<0.001		<0.001
COPPER (CU) TOTAL			0.01			
COPPER (CU) DISS				<0.01	<0.01	<0.01
CHROMIUM (CR) TOTAL	<0.005	<0.005				
CHROMIUM (CR) DISS				<0.02		<0.02
IRON (FE) TOTAL	0.03	0.01	0.03			
IRON (FE) DISS				<0.03	<0.03	0.18
LEAD (PB) TOTAL	<0.005	<0.005	0.01			
LEAD (PB) DISS				<0.01		<0.01
MANGANESE (MN) TOTAL	<0.005	<0.005				
MANGANESE (MN) DISS				<0.02		0.97
MERCURY (HG) TOTAL	<0.0002	<0.0002				
MERCURY (HG) DISS				<0.001	<0.001	<0.001
MOLYBDENUM (MO) DISS				<0.005		<0.005

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 11. SUMMARY OF WATER QUALITY SAMPLING - SAND COULEE Groundwater

SAMPLING SITE	TRACY PUB SPLY	S COUL PUB SPLY	STOCKETT PUB SPLY	SF8	SF16	SF20
SAMPLE DATE	05/18/79	05/18/79	06/05/73	08/20/80	08/20/80	08/20/80
NICKEL (NI) DISS				<0.03		<0.03
SELENIUM (SE) TOTAL	<0.002	<0.002				
SELENIUM (SE) DISS				0.016		<0.005
SILVER (AG) TOTAL	<0.005	<0.005				
SILVER (AG) DISS				<0.005		<0.005
ZINC (ZN) TOTAL			0.02			
ZINC (ZN) DISS				0.05	0.08	0.03
OTHER PARAMETERS						
BORON (B)				<0.10	<0.10	<0.10
SILICA (SIO2)				8.1		3.2

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

drainages are groundwater recharge zones. Drainage from mines obviously has a short-term component from precipitation and the more steady baseflow from the mines probably reflects its connection with a larger groundwater system in the coal.

Bedrock formations in the drainage also may receive groundwater recharge in the Little Belt Mountains south of the Sand Coulee Creek drainage. The general direction of groundwater flow probably is northward. It is thought the source of Giant Springs near Great Falls is discharge from northward flowing groundwater in the Mission Canyon Formation.

Alluvium along stream channels in the drainage is recharged by precipitation and infiltration of streamflow. Some water wells in alluvium from Sand Coulee to Tracy are reported to have become polluted due to infiltration of acid water from streams (J. Mittal, pers. comm., August 1980).

Groundwater discharge is to springs and wells and probably to streams in some areas. Springs are present in several geological units - particularly the basal section of the Kootenai Formation.

DESCRIPTION OF MINES

Each discharging mine in the Sand Coulee drainage was carefully examined to determine its characteristics and condition. Table 12 summarizes the mine conditions and the location, condition and effluent flow of each individual mine described in this section.

Mine SCM 2

SCM 2 is located on the east side of Sand Coulee about one mile southeast of the town of Sand Coulee at 19N04E23ADCB. Ernest Chartier is the present landowner. This mine is part of the old Carbon Mine once operated by the Cottonwood Mining Company. The mine portal is no longer visible due to the collapse of the large sandstone bed which once rested on top of the coal. A large pool of water 5 feet wide by 30 feet long and about 3 to 4 feet deep, is located at the base of the hillside where the mine opening once existed. The pool is fed by discharge surging up from the abandoned portal and flowing at the rate of over 300 gpm. The water flows from the northeast side of the pond into a ditch where it joins Sand Coulee approximately 50 feet from the old portal. Sand Coulee upstream from SCM 2 is a natural stream fed by springs and runoff and appears to be of good quality. The stream channel below the confluence of SCM 2 is heavily encrusted with iron precipitate.

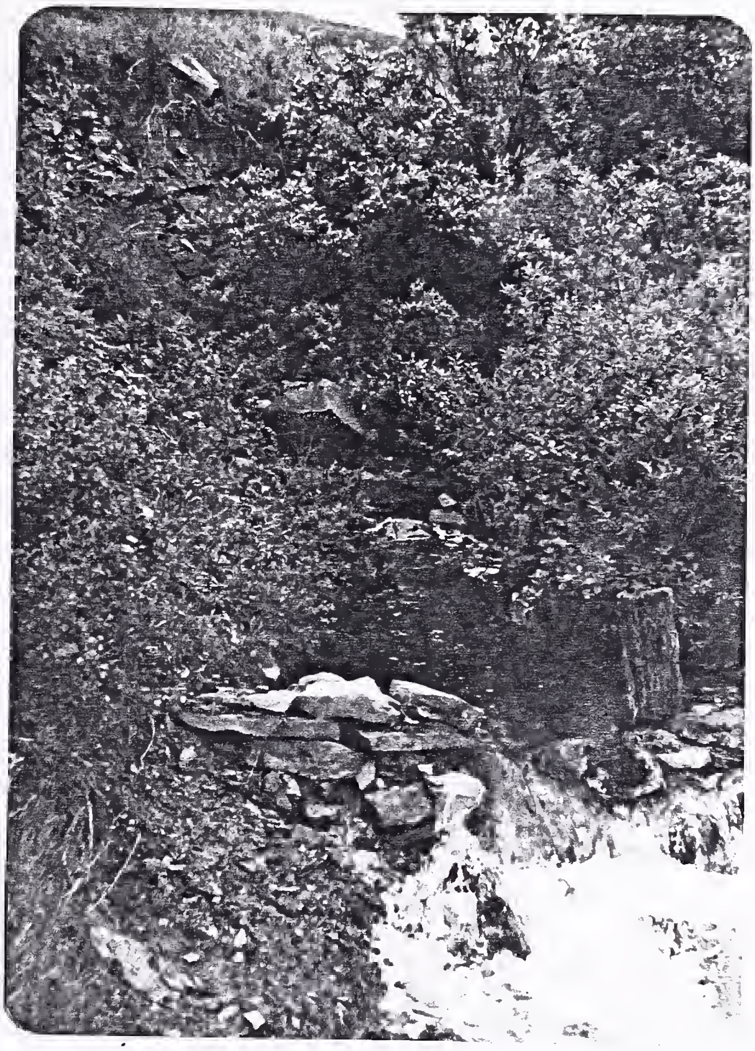
SCM 2 is in an area which contains large accumulations of mine waste piles although no waste is actually present at the site of the portal. The waste is located along both sites of Sand Coulee and extends for several hundred yards downslope from the mine.

Discharge from SCM 2 has varied from a low of 43 gpm on March 5, 1981, to 600 gpm on July 13, 1981 (Table 6). Because of the tremendous volume of water pouring out of the mine during the period of April 1981 through June 1981, the discharge was impossible to measure and therefore was estimated. The Montana Bureau of Mines and Geology estimated the flow to be between 500 and 1000 gpm on May 28, 1981.

TABLE 12. MINE ADIT DESCRIPTIONS OF DISCHARGING MINES IN THE SAND COULEE AREA

Characteristics	SCM 2	SCM 3	SCM 4	SCM 5	SCM 6
Adit Condition	Partially Open	Collapsed	Completely Caved	Open	Completely Caved
Roof Materials	Sandstone	Earthen	Earthen	Fractured Sandstone	Sandstone & Soil
Floor Material	Flooded	Covered W/Debris	Covered W/Debris	Flooded and Covered W/Sludge	Unknown
Timbers Present	Partial Support in Front of Adit	None	None	Partial Support in Opening	None
Debris Present	Mixed W/Water in Adit	Scattered in Front of Adit	Covering Front of Adit	Floor Covered	Scattered in Front of Adit
Width (Ft)	3 - 4	10 Feet	10 Feet	6	15 Feet
Height (Ft)	2	Unknown	Unknown	4	Unknown
Ht. of Material Above Adit (Ft)	60 Feet	20 - 40	60	30 - 40	60 Feet
Extent of Water Present	Mostly Flooded	Seepage from Bottom	Seepage from Caved Materials	Adit filled to Within 4' of Roof	Flow Seeps from Caved Materials
Length of Open Adit	2 - 5 Feet	None	None	10 - 20 Feet	Unknown
Coal Seam Thickness	Unknown	Unknown	Approximately Five Feet	Unknown	Unknown

Characteristics	SCM 7	SCM 8	SCM 9	SCM 11	SCM 15
Adit Condition	Completely Caved	Mostly Caved	Completely Caved	Open & Passable	Completely Caved
Roof Materials	Soil	Sandstone & Soil	Soil	Fractured Sandstone	Soil
Floor Material	Unknown	Debris Covered	Debris Covered	Damp, Soft Mud like Materials; Some Debris	Unknown
Timbers Present	None	None	None	For Roof Support & Side Structure	None
Debris Present	Scattered in Front of Adit	Covering Floor	Scattered in Front of Adit	Small Amount on Floor	Covering Front of Adit
Width (Ft)	10 - 15 Feet	7 Feet	10 Feet	10 Feet	10 Feet
Height (Ft)	Unknown	3 Feet	Unknown	6 Feet	Unknown
Ht. of Material Above Adit (Ft)	60 Feet	20 Ft. of Sandstone	40 Feet	40 - 50 Feet	50 Feet
Extent of Water Present	Flow Seeps from Caved Materials	None in Adit	Flow Seeps out in Front of Adit	None	Flow Seeps from Caved Materials
Length of Open Adit	None	At Least 10 Feet	None	At Least 50 Feet	None
Coal Seam Thickness	Unknown	Unknown	Unknown	Approx. 5 Feet	Unknown



SCM 2 - Portal and Mine Discharge
May 21, 1981

SCM 2 - Mine Discharge Flowing into Sand Coulee
May 21, 1981

For the twelve month period the flow rate from SCM 2 has averaged in excess of 330 gpm. In his 1969 and 1970 study, McArthur (1970) reported the discharge from SCM 2 to reach a high of 150 gpm in October 1969 and a low of 45 gpm in March 1970. The discharge in July 1970 was back up to 135 gpm which is between 200 to 300 gpm lower than the flow measured in July 1981.

Numerous analyses of the quality of water discharging from SCM 2 have been made during the period 1969 to 1981 (Table 8). The mine discharge is extremely poor quality and is characterized by low pH (2.6 to 2.9), high specific conductance (4500 to almost 8000), high acidity (4000 to 5260), and high sulfate (4600 to over 5800). Metal concentrations in the mine water are high with some exceptionally high levels of iron (1270 mg/l), arsenic (30 ppm), and aluminum (608 mg/l).

Mine SCM 3

SCM 3 is located along the east side of Sand Coulee about 1200 feet downstream from SCM 2 and less than one mile southeast of the town of Sand Coulee at 19N04E23ADAB. SCM 3 also was part of the Carbon Mine operation. Ernest Chartier is owner of the land. The mine portal has completely collapsed and is filled by rock and soil from the overlying roof materials. The area adjacent to the old mine is covered with a 10 to 15 foot high pile of black colored mine wastes (mostly shale). These wastes extend over an area of about 4000 square feet. A small pond about 8 feet wide by 20 feet long is located about 10 feet from the old mine entrance. The pond is fed by mine discharge which flows from the material filling the portal. Overflow from the pond drains into an iron stained ditch and hence into a wood stave pipe where it drops about 3 feet into Straight Creek.

Discharge from SCM 3 was fairly consistent during the past twelve month period (Table 6). Some fluctuations did occur in April 1981 and May 1981 which reflected the spring runoff and precipitation periods (Table 6). The lowest flow was 7 gpm in September 1980 and

SCM 3 - Mine Portal and Discharge
May 21, 1981

again on July 13, 1981. The highest flow recorded was 26 gpm on May 28, 1981. Flow recorded during McArthur's study in 1969 to 1970 was 20 gpm. There is apparently some contribution to the mine discharge from precipitation, however, this contribution does not appear to be as substantial as is indicated by mine SCM 2. One possible explanation is less extensive underground workings than SCM 2 and the possibility that SCM 2 intercepts most of the subsurface water before it reaches the SCM 3 workings.

The mine effluent quality of SCM 3 is very poor and is similar to the quality of mine discharge from SCM 2. Table 8 shows the results of analyses of mine water from SCM 3 for several sampling periods starting in 1969 and including recent samples. The mine discharge has a low pH, and very high concentrations of acidity, sulphate, aluminum iron and zinc.

Mine SCM 4

SCM 4 is located along the east slope of Number Five Coulee and approximately 600 yards downslope from the confluence of Giffen Coulee and Number Five Coulee at 18N04E14ACD. The town of Stockett is located about four miles northeast of the mine area. SCM 4 is one of several abandoned mines located in this area which at one time comprised the Giffen Mine Company which is reported to be the largest producing mining operation in the Sand Coulee District. The area is covered with vast piles of coal mining wastes which cover an area estimated to be over 10 acres. Several pieces of old mining equipment and the facilities are scattered throughout the mining sites and a large tipple spans the area south of SCM 4. Ralph Singles is the current landowner.

SCM 4 is reported to be the largest mine in the Sand Coulee area and contains underground workings which extend for several miles both to the west and the south. The entrance to the main adit at SCM 4 is collapsed and covered with rock and soil. A deep pool of water covering an area about 1000 square feet is located along the face of the portal. The pool is fed from mine effluent which apparently discharges from the base of the portal.

Overflow leaves the pool through an 8-inch diameter plastic pipe and enters a 150 foot long iron stained ditch before it enters Five Mile Creek. Five Mile Creek eventually flows into Cottonwood Creek approximately five miles downstream.

Discharge measurements from Mine SCM 4 (Table 6) show effluent rate from SCM 4 is high in comparison to other mines in the Sand Coulee area. The lowest measurement made was 150 gpm during October 18, 1979, and again September 21, 1980. For most of the 1981 monitoring period (April to May 1981) the discharge from SCM 4 has exceeded 250 gpm. A high of 359 gpm was recorded by the Montana Bureau of Mines and Geology on May 28, 1981.

SCM 4 - Mine Portal and Collection Pond

SCM 4 - Pond Overflow and Ditch

SCM 4 did not exhibit a large response to precipitation as did most of the other mines in the area; however, because of the vast extent of the underground workings, it is possible that, because of an increase in length of travel or a greater capacity to store more water, the mine discharge rate is less affected. Flow rates reported by McArthur (1970) were estimated at 300 gpm during his study period; however, he reported a discharge rate of 500 gpm in July 1970.

The quality of discharge from SCM 4 is poor but it is somewhat better than the discharge from most other mines in the Sand Coulee area. Results of analyses of water from SCM 4 are listed in Table 8. Samples tested in 1980 and 1981 show the pH to vary from 3.3 to 5.5, and show the effluent has a high specific conductance, acidity, sulfate, and iron.

Mine SCM 5

SCM 5 is located about 700 to 800 feet up an unnamed coulee west of the highway and approximately 1/2 mile southwest of the community of Sand Coulee at 19N04E14DDCD. SCM 5 was part of the Brown Mine. The mine portal is still partially open and extends back into the hillside for over 100 feet. A three foot deep pool of mine water extends from 15 feet outside the entrance back into the entire length of open adit. The pond overflow discharges into a stream which passes within 30 feet of the portal. This stream is apparently fed from springs upstream from the mine and appears to be of good quality.

The stream below SCM 5 becomes very turbid and milky colored from the contribution of mine discharge. The stream channel below the water level is covered with a white slimy precipitate (probably aluminum hydroxide). Parts of the stream channel above the water level are reddish orange colored from the iron hydroxide precipitate. The entire stream channel from the mine discharge location to its confluence with Sand Coulee approximately 200 yards downstream exhibits a white chalky color.

SCM 5 - Mine Portal and Pond Overflow

Unnamed Stream Downstream From SCM 5 Discharge

Mine wastes including carbonaceous shales and scoria cover the entire hillside along the north side of the unnamed stream from just above SCM 5 to Sand Coulee. These wastes are estimated to be up to 20 feet thick in places and cover an area estimated to be over one half acre in size.

Discharge from SCM 5 has been highly variable throughout the monitoring program (Table 6). On April 3, 1981, when the program was first initiated there was no flow from the pool at the front of the mine but on April 20, 1981, the flow was measured at 40 gpm. As April 1981 was extremely dry and only three measurable rainfalls occurred and totaled only 0.05 inch, the resumption of flow during the latter part of April cannot be explained. The recorded flow during the next three months was 31 gpm on May 7, 50 gpm on May 21, a high of 71 gpm on June 13, and a low of 19 gpm on July 8. In August 1980 the flow was measured at 15 gpm. Measured flow rates from the mine correlate well with precipitation events and the mine responds fairly rapidly to rainfall. Measured flows during this study were somewhat lower than those reported by McArthur (1970).

The quality of discharge from SCM 5 is listed in Table 8 for numerous analyses completed during 1980 and 1981 and also during 1969 and 1970. Water quality of the discharge has been relatively constant. Quality of water from SCM 5 is poor and it has a low pH, high specific conductivity, a high concentration of acidity, sulfate, aluminum and iron.

Mine SCM 6

SCM 6 is located less than one quarter of a mile southwest of the town of Sand Coulee at 19N04E13CBD. This mine is one of several mines located along the hillside which were once operated by the Nelson Mining Company. Ernest Chartier is the present landowner.

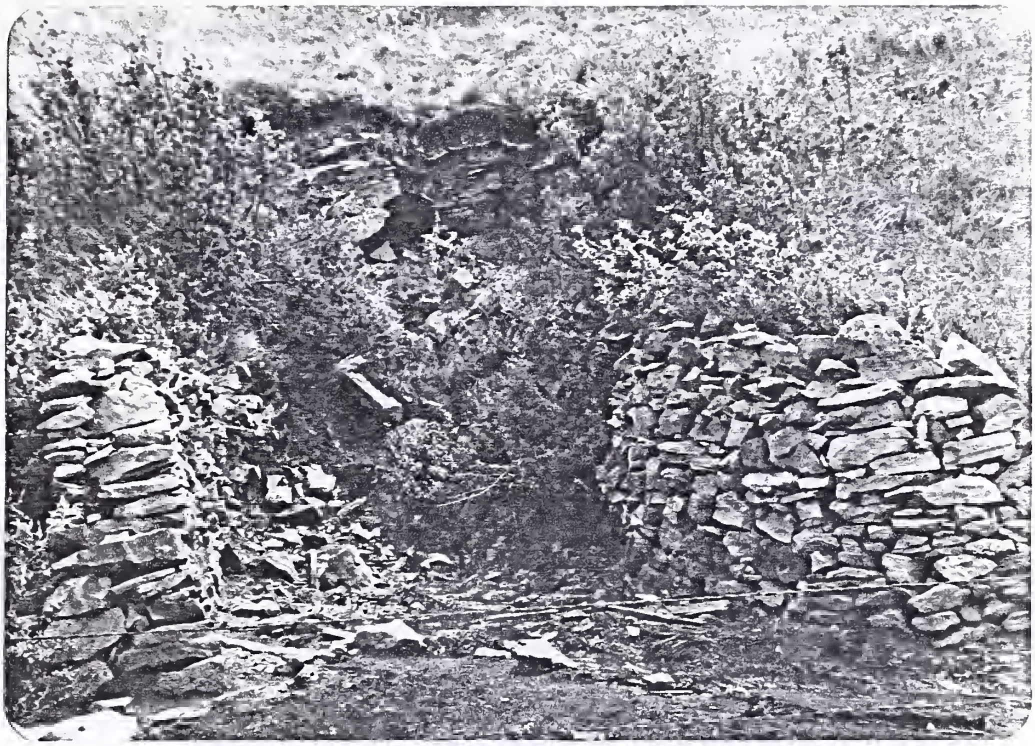
The discharging adit is located at the top of a 50 foot pile of discarded coal and mine wastes which extend for an estimated 1500 feet

along the hillside south of Sand Coulee. Sand and gravel fill dumped into the mine entrance and the sandstone over the coal have collapsed and blocked the entrance. Mine effluent is discharging from the fill near the bottom of the entrance. This effluent flows along a narrow ditch for about 80 feet where it is contained by a 4 foot wide by 20 foot long pond excavated out of the top of the mine waste pile. The pond discharge then flows southeastward along the top of the waste pile and eventually into a channel at the base of the pile. The discharge is then diverted into a culvert under the highway where it dumps into Sand Coulee.

The hillside along the east side of the highway extending for over 2000 feet south of the town of Sand Coulee is covered with mine wastes. These wastes are the accumulation of materials excavated from five different mines located along this hillside and cover almost ten acres of ground. A mine dump containing several large piles of additional mine wastes and scoria is located about 200 yards further south along Mining Coulee. Mining Coulee Creek joins Sand Coulee just below the mine dump location.

Another adit (named SCM 6A) located along the hillside about 50 yards north of SCM 6 started to discharge some mine effluent in June 1981 during the period of heavy precipitation. This discharge was flowing at the rate of about 3 gpm along a small ditch which runs almost straight down the hillside. Some flow eventually dissipates in the coal wastes at the bottom of the hill and the remainder drains into Sand Coulee.

The discharge from Mine SCM 6 has been very erratic during the past year and has fluctuated from a low of 1.8 gpm on August 14, 1980, to a high of 250 gpm on May 28, 1981, an increase of almost 1400 percent. The large increase in May 1981 is believed largely due to precipitation; however, the increase in April 1981 occurred during a period of little recorded precipitation and after an abnormally dry fall and winter season.

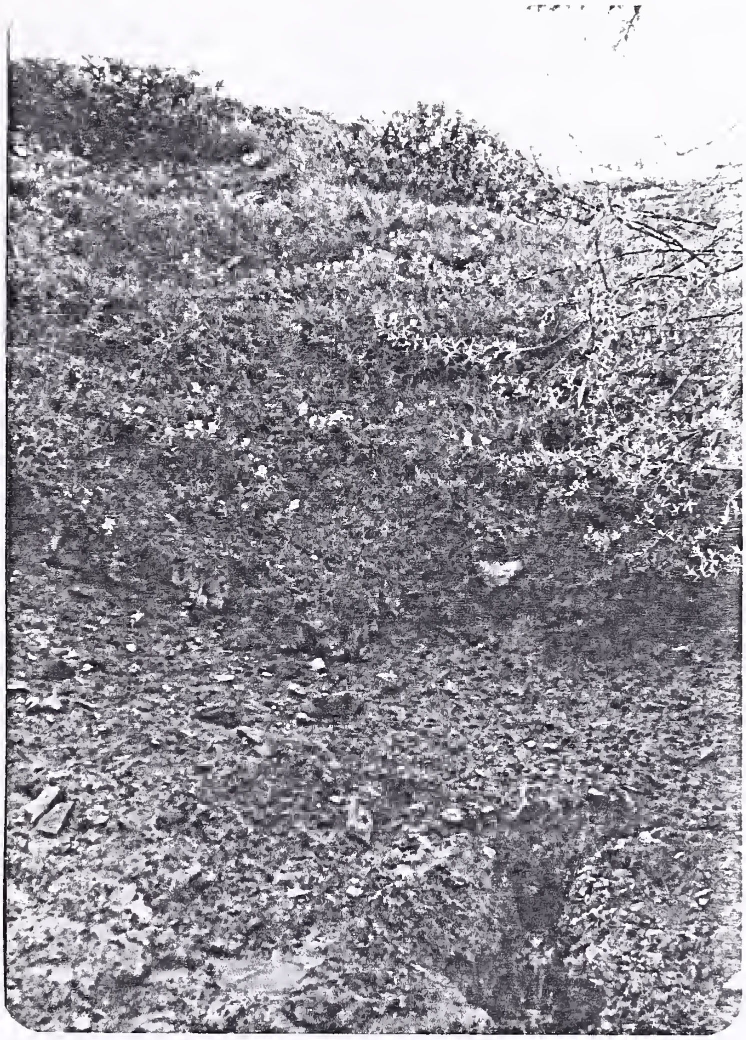


SCM 6 - Mine Portal and Discharge

Effluent from SCM 6 has a very low pH which has remained fairly consistent. McArthur recorded the pH at 2.5 during his study which compares to the pH of 2.3 to 2.5 measured during this investigation (Table 8). Specific conductance was reported by McArthur to be 5730 μmhos/cm which is similar to the 5900 μmhos/cm measured in August 1980. Effluent from SCM 6 is very poor in quality with low pH and very high concentrations of total dissolved solids, sulfate, acidity, aluminum, iron and zinc.

Mine SCM 7

SCM 7 is located about one-half mile northeast of the town of Tracy (19N05E7ABD) and was once part of the old Pierce Mine. The land is owned by Gene Johnson. The adit entrance is completely filled with soil and is covered with vegetation. The only evidence of the adit is the cut in the face of the hillside and some discarded coal and mine wastes downslope from the old adit site. Approximately 20 feet of the coulee below the old entrance is filled with sand and gravel to a depth of between 5 and 10 feet. The mine discharge seeps out from the face



SCM 7 - Mine Portal Site and Discharge

of the fill just above the base. The discharge flows along a small ditch for about 50 feet where it is impounded by a small dam excavated out of the accumulated mine wastes. Overflow leaves the dam and flows down the coulee where it disperses into a wheat field. The high acidity of this water has killed vegetation along its flow path and has ruined approximately five acres of once productive farmland. Discharge onto the wheat field has created a large marsh which is expanding.

A parshall flume and continuous recorder were installed in the ditch below the discharge site. The purpose of this installation was to monitor the mine effluent for comparison with precipitation events. A correlation between precipitation and effluent rates would suggest that a method to restrict or eliminate infiltration by rain and snowmelt into the drainage area above the mine could conceivably reduce or stop flow.

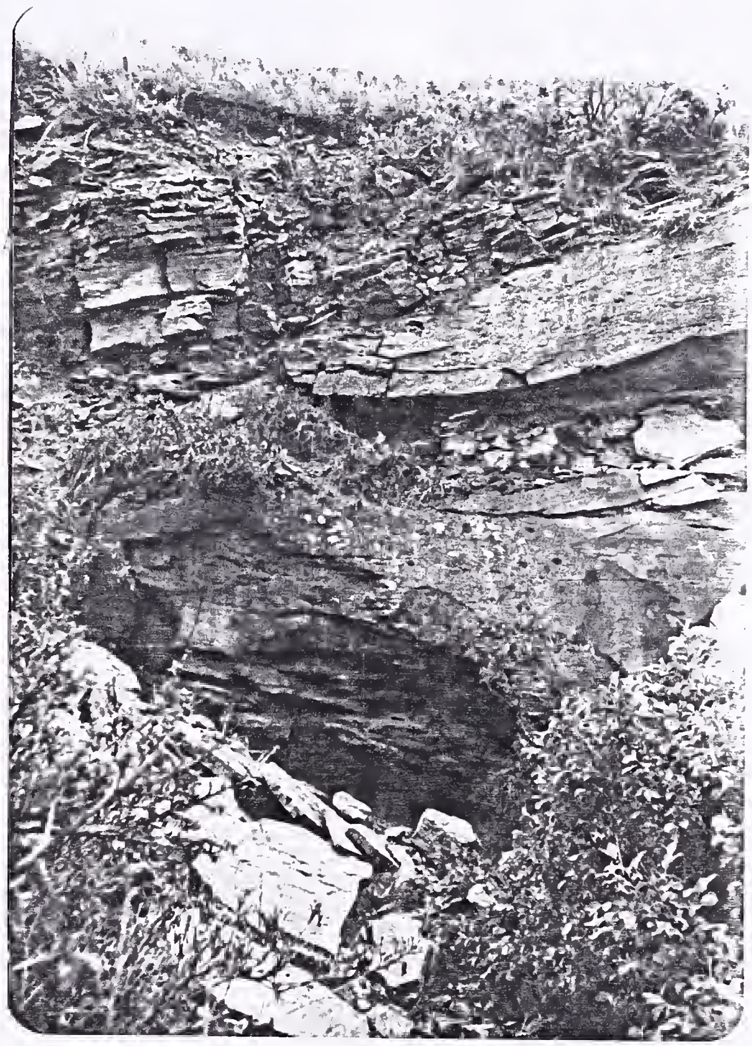
The flume was installed and monitored for a period of four months. Average flow rate was about 11 gpm for this period with a maximum of 15.3 gpm May 14, 1981, and a minimum of 7.4 gpm June 17, 1981. The flow rate remained almost constant during this time with slight increases in flow rates in April and early May and a reduction in flow rates in late May and June and increasing again in July. There does not appear to be a detectable correlation between the increased discharge and rainfall. Precipitation recorded at Great Falls and at Sand Coulee was not reflected in the flow or mine effluent. There are some increased flows noted on the recorder charts which appear at about the same time as some precipitation events; however, these increases are sporadic and are not consistent with all events. It is assumed that the increases which are apparent on the charts are the result of runoff increasing the flow in the ditch rather than an increase in mine effluent.

The quality of the effluent from SCM 7 is extremely poor and is highly acidic with a pH measured at 2.6 in August of 1980 and 2.3 in April 1981. McArthur (1970) reported the pH of the mine discharge to be 2.4. Specific conductance for the same monitoring periods is 3300 and 3660 respectively and 2820 during McArthur's study (Table 8). All concentrations of constituents typical of very poor quality coal mine effluent, i.e. acidity, sulfate, aluminum and iron, are very high.

Mine SCM 8

SCM 8 is located about one quarter mile east of the town of Tracy (19N05E7CACD) and is part of the old Anaconda Mine group. Several other mines are located along the hillsides on each side of the coulee below SCM 8. The mine entrance is excavated in the massive sandstone overlying the coal beds and much of the sandstone has broken away from the roof and accumulated around the portal. The portal however, is partially clear and the mine adit is open for 30 to 40 feet into the hillside. The area below the portal is covered with approximately 50 feet of mine wastes which extend for several hundred yards along the hillside.

The mine discharge emerges from the mine wastes about 50 feet from the portal where it flows through a 6 inch high by 10 inch wide wooden trough. Discharge from the trough flows down the waste pile into a ditch and eventually enters a stream in the coulee. This stream is partially fed from springs located at the upper end of the coulee but streamflow contains a significant quantity of mine discharge. The stream flows northward along the foot of a hill for about 300 yards to a grain field and is dispersed.



SCM 8 - Mine Portal

SCM 8 - Mine Discharge

Three other mines located upstream from SCM 8 have not had any noticeable discharge during the investigation nor did McArthur (1970) report flow from these mines during his study. However, on May 21, 1981, after twelve days of rainfall in a thirteen day period, these three mines were discharging a combined total of over 130 gpm. One mine almost directly across the coulee from SCM 8 was flowing at the rate of over 100 gpm. This discharge continued into June although the flow had diminished and had stopped completely by July 8, 1981. There is little doubt that precipitation was the source of the discharge from these mines.

The rate of flow from SCM 8 has been highly variable and has ranged from a low of 14.3 gpm March 5, 1981, to over 300 gpm on May 21, 1981 - only two months later (Table 6). For most of the monitoring period, flow from SCM 8 has been high and has exceeded 150 gpm. On October 18, 1979 the discharge was estimated at 15 gpm and during McArthur's study flows ranged from a low of 20 gpm to a high of 60 gpm.

There is no doubt that most, if not all, of the discharge from SCM 8 is precipitation related. The high flow rates in the spring are largely due to contribution from snowmelt and high flows in the late spring and early summer mainly result from rainfall.

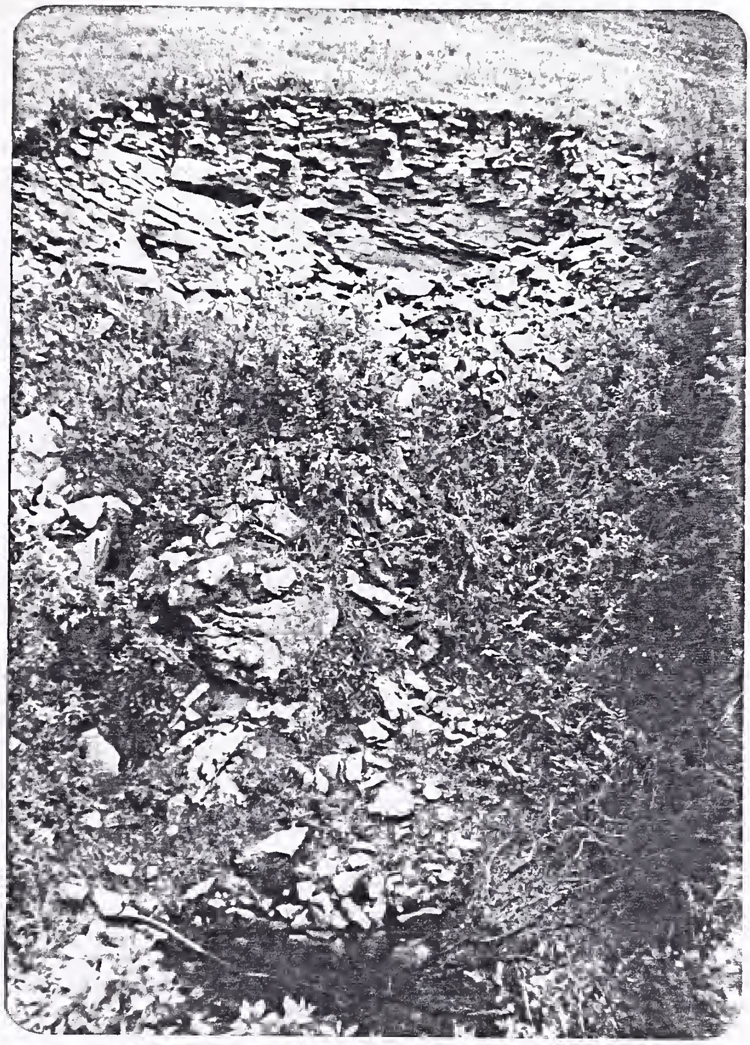
The quality of water discharged from SCM 8 is poor with a pH ranging between 2.7 and 3.0 and a specific conductance varying from 1600 to about 2500 μmhos/cm. Results of numerous analyses of effluent from SCM 8 show the effluent to be typical of acid mine drainage; however, concentrations of acidity, sulfate, aluminum, and iron are considerably lower than most mine discharges in the Sand Coulee drainage.

Mine SCM 9

SCM 9 is located up the Cottonwood Drainage about 1½ miles southeast of Stockett at 18N05E6CDB. SCM 9 is part of the old Number 6 Mine and is located on land owned by Bill Singles. The mine area is located on a fairly steep hillside above a rather narrow and steep coulee. The entrance is blocked with sand and gravel fill and collapsed roof material. The coulee below the entrance is partially filled with mine wastes which have created a dam across the coulee. A small pool of water is located in the base of the coulee between the portal and dam. Discharge from the mine emerges from the mine wastes about 100 feet beyond the portal. This discharge flows in a northwesterly direction along the side of the hill for about one-half mile before it joins Cottonwood Creek about one mile above the town of Stockett.

There are several abandoned mines located along the hillside above Cottonwood Creek and much of the waste from these mines is piled along these hills. The wastes from SCM 9 are primarily located along the coulee downslope from the mine.

Discharge from Mine SCM 9 has been highly variable and has ranged from a low of 8 gpm recorded on October 18, 1979, to a high of 166 gpm on June 13, 1981. Table 6 lists the discharge measurements for SCM 9



SCM 9 - Portal With Small Pond Below Portal

SCM 9 - Mine Discharge

from October 1979 to July 1981. The increased flow rates measured the latter part of May through June are the result of the heavy precipitation which occurred during this period. The discharge on June 13, 1981, of 166 gpm was an increase of over 1500 percent over the discharge rate of 10.7 reported on March 5, 1981. There is little doubt that much of the flow from SCM 9 results from precipitation. Flow rates from SCM 9 during McArthur's study ranged between 15 and 25 gpm.

Quality of discharge from SCM 9 is extremely poor (Table 8). The pH of the mine effluent from SCM 9 has ranged from a low of 2.4 to a high of 2.9. Specific conductance has been relatively constant (6170 to 6826 µmhos/cm). The effluent contains very high concentrations of sulfate, acidity, iron, aluminum and zinc.

Mine SCM 11

SCM 11 is located less than one-quarter mile west of the town of Sand Coulee at 19N0413CBA. The mine entrance is excavated into sandstone overlying the coal. The entryway is timbered and, although some rock debris has accumulated in front of the adit, the portal opening is still over 5 feet wide and 6 feet high. The adit is open for approximately 100 feet into the hillside.

Discharge from the mine emerges from the mine wastes over 100 feet away from the portal. This discharge flows down the face of a mine waste pile, then through a section of pipe beneath a private road and then is discharged into Sand Coulee Creek. The area about 50 feet below the portal is entirely covered with coal and mine wastes. These wastes extend over 150 feet to the edge of Sand Coulee Creek and are piled at depths between 5 to over 10 feet thick.

The rate of discharge from Mine SCM 11 is related to precipitation. Less than 1 gpm was measured on March 5, 1981, and during April 1981 no flow was observed (Table 6). It was only after the major rainfall

SCM 11 - Mine Portal

events in May 1981 that significant discharge occurred from SCM 11. This discharge increased to 38 gpm during the latter part of May which coincides with the precipitation occurring during the same period. On July 8, 1981, the flow from SCM 11 had decreased to 7.5 gpm however, it then increased to 17.9 gpm on July 13, 1981, just after a rain storm. SCM 11 was one of the mines McArthur reported as having intermittent discharge and he recorded no flow from this mine.

The quality of water from Mine SCM 11 is poor with low pH (2.8 to 3.0) and moderate concentrations of dissolved solids, sulfate, acidity, iron, and zinc (Table 8). This mine principally adds acidity to water and has one of the lowest concentrations of metals in the Sand Coulee drainage.

Mine SCM 15

SCM 15 is located about one mile northeast of Tracy approximately 1500 feet northeast of SCM 7 (19N05E7AAAA). This mine is on land owned by Gene Johnson and is believed to be part of the old Carbon Mine. The mine entrance has completely collapsed and is covered with rock from the overlying sandstone bed. There is apparently another portal just adjacent to the discharging one which has a timbered entry and is still partially open. Discharge from the one mine emanates from the base of the pile of collapsed sandstone and collects into a small pond. The overflow then continues down-slope along a manmade ditch from about 200 feet, then flows along another ditch adjacent to a grain field and eventually disappears into the subsurface. Mine wastes from the SCM 15 mine are considerable and extend laterally from 60 feet to over 100 feet beyond the portals. The piles reach a depth of over 12 feet.

SCM 15 - Mine Portal With Small Iron
Stain at Pool at Base of Rock Fill

The quantity of discharge from the SCM 15 mine has been generally small compared to other discharging mines in the Sand Coulee area (Table 6). The flow rate averaged about 7 gpm during April and early May 1981 but increased to over 20 gpm on May 21, 1981, after the precipitation period in May. The discharge in June was measured at 13 gpm and in July had dropped to 10 gpm. The effluent rate in August 1980 was measured at 4.5 gpm. There does not appear to be a good correlation between mine discharge and precipitation events for SCM 15. Although discharge did increase after the extended precipitation in May 1980, no detectable responses or increases were observed after significant rainfall in June and July. It is believed that precipitation does supply most of the recharge to SCM 15; however, there may be either a very sudden flow increase of short duration or a long lag time between rainfall events increased flow that could only be determined from continuous monitoring.

The quality of discharge from SCM 15 is good and is not typical of the discharge from any other mines in the Sand Coulee area (Table 8). The pH of the mine effluent in August of 1980 was 7.7 and the specific conductance was 1000 μmhos/cm. In April 1981 the pH was measured at 6.3 and the conductance at 1000. Gene Johnson, the landowner, waters his livestock from the discharge of SCM 15 and maintains the water has always been of good quality.

IMPACTS OF ACID MINE DRAINAGE

Acid drainage has caused impacts to both land and water resources in the Sand Coulee drainage. Land impacts involve destruction of vegetation in areas where mine drainage flows onto agricultural or grazing lands. Damage to water resources includes degredation of surface water and groundwater quality and increases in surface water and groundwater flow. Typically, acid drainage flows to and enters the nearby stream causing significant degradation in stream water quality and increases in the streamflow. Water quality impacts on streams generally are severe. Most streams receiving AMD in Sand Coulee are rendered unfit for domestic, livestock or irrigation use and the aquatic communities are essentially destroyed.

Groundwater can be impacted both in quality and in quantity. Acid drainage in streams percolates into the subsurface and joins the existing groundwater system. This can increase groundwater flows, which in itself may not be harmful; however, the acid drainage is very poor in quality and normally would cause substantial groundwater degradation.

Another adverse impact caused by acid mine drainage is one of aesthetic values in stream channels. Many stream channels in the Sand Coulee drainage are covered with a thick precipitate of iron and the water is discolored and turbid. This creates an unsightly condition which often leads to other abuses of the stream such as disposal of garbage, tires and other debris.

There are no quantitative criteria for assessing overall resources impacts of mine drainage, however each discharging mine was evaluated and semi-quantitatively ranked relative to damage to land and water resources. This ranking provides a ready comparison of environmental impacts of each of the discharging mines in the Sand Coulee drainage (Table 13).

TABLE 13. HYDROLOGICAL IMPACTS OF ABANDONED COAL MINES ON RESOURCES IN THE SAND COULEE AREA

Mine Number	Agri. Lands	S.W. Quality	S.W. Quantity	G.W. Quality	G.W. Quantity	Esthetic Value	Total Impact*
SCM 2	0	L	L	L	S	M	2
SCM 3	0	M	M	M	S	S	3
SCM 4	S	L	L	L	M	L	1
SCM 5	0	M	M	M	M	S	4
SCM 6	0	S	S	M	M	M	8
SCM 7	M	0	0	S	S	M	6
SCM 8	S	0	0	S	S	S	9
SCM 9	S	M	S	M	S	S	5
SCM 11	0	S	S	M	S	S	7
SCM 15	S	0	0	S	S	0	10

Notes: S.W. is Surface Water, G.W. is Groundwater
Agri. Lands is Agricultural Lands
0 - None L - Large
S - Small V - Variable
M - Moderate U - Unknown

* Total impact represents a summation of impacts and gives a relative ranking of the overall impact of each mine.

In the entire Sand Coulee drainage, it is estimated that 25 miles of stream are significantly degraded in quality by AMD. Groundwater through much of the drainage also is severely impacted and the shallow aquifer present along Sand Coulee Creek and its tributaries, in many areas, is unsuitable for domestic, livestock, or irrigatiion use. This condition of groundwater and surface water degradation has existed in Sand Coulee for many years and the presence of both polluted groundwater and surface water has resulted in development of springs on slopes along the edge of the valleys and deep wells into formations underlying and unaffected by polluted groundwater.

Specific Mine Impacts

An evaluation was made of specific resources impacts from each discharging mine in the Sand Coulee drainage. The effluent from SCM 2 enters Sand Coulee above the community of Sand Coulee and a large flow of poor quality mine water enters a small flow of good quality water in the stream. SCM 2 has a major degrading impact on the water quality of Sand Coulee and seepage of the surface water into the underlying groundwater system probably increases the amount of groundwater and significantly degrades its quality. Similarly, the discharge from mine SCM 3 is very poor in quality and it enters Sand Coulee and causes the same type of impacts as SCM 2. SCM 3 however, has a much smaller flow and has less impact on Sand Coulee and the underlying groundwater system than does effluent from SCM 2.

Mine discharge from the Giffen Mine (SCM 4) is from the largest mine in the Sand Coulee area and is a large flow of very poor quality water. This water enters the upper end of Number Five Coulee. The large flow and poor quality causes this mine discharge to have a severe impact on both the quality and quantity of surface water in the drainage. Seepage from the polluted stream probably has a significant impact on the underlying groundwater system causing an increase in groundwater flow and a probable significant degradation in groundwater quality. Acid waters from this mine also spread out over a considerable area and impact vegetation in the vicinity of the mine.

A small to medium quantity of water discharges from SCM 5 which is an unnamed ephemeral coulee just west of the highway and approximately one half mile southwest of the community of Sand Coulee (Exhibit 1). Effluent from this mine is of very poor quality and has a severe impact on the receiving stream (when it is flowing) and has a moderate impact on Sand Coulee. This stream also probably degrades groundwater quality in the unnamed coulee and in groundwater underlying Sand Coulee.

Mine SCM 6, located just southwest of the town of Sand Coulee, discharges water from the adit and the water runs down over mine waste dumps. Flow from SCM 6 is relatively small but the quality is very poor. Water from the mine eventually flows to Sand Coulee and degrades both surface water and groundwater resources in Sand Coulee.

A relatively small amount of poor quality acid water exists in SCM 7. This mine is on a hillside, approximately one-half mile north of the town of Tracy. The mine discharge flows along a small ditch for about fifty feet to a dam, then overflows the dam and flows down a coulee where it disperses into cropland on the Sand Coulee Creek flood plain. This water has killed vegetation along its flow path and has ruined approximately 5 acres of once productive farmland. Discharge onto the cropland has created a large marsh which is expanding. This mine has the greatest impact on agricultural lands of any mine in the drainage. The seepage does not reach surface waters and has no impact on Sand Coulee Creek. The acid water very probably infiltrates however, creating a zone of poor quality groundwater beneath the cropland.

Effluent from SCM 8 discharges from an adit located just southeast of Tracy and flows down a hillside. Vegetation along the flow path, and a small area of cropland, have been damaged by the acid waters. The water does not reach Sand Coulee Creek and does not impact surface water but it very probably has an adverse impact on groundwaters beneath the cropland.

Acid water from SCM 9 flows along a hillside for about one-half mile before it joins Cottonwood Creek upstream from the town of Stockett. The discharge from SCM 9 is a moderate quantity of very poor quality water. The discharge rate is highly variable and the discharge has destroyed vegetation along the hillside. Effluent from SCM 9 degrades water quality in Cottonwood Creek, contributes a small amount to the flow of the creek, and probably significantly degrades quality of groundwater beneath the stream.

SCM 11 is located just west of the town of Sand Coulee. Discharge from the mine emerges from mine waste piles over 100 feet away from the portal. The discharge flows down the face of the mine waste piles, then enters Sand Coulee. Flow from this mine is small, the quality is poor and the mine has an adverse impact on surface water quality in Sand Coulee and probably has an adverse impact on groundwater in the vicinity of the mine and underlying Sand Coulee.

The discharge from SCM 15 is located about one mile northeast of Tracy. A small amount of fair quality water exits the mine and flows down a gentle slope along a manmade ditch and eventually disappears into the subsurface in the adjacent cropland. Effluent from this mine probably has no impact on cropland, no impact on surface water quantity (it is completely absorbed by the cropland) and probably has a small impact on groundwater quantity underlying the seepage area.

In addition to mines with continuous drainage of acid water, a number of mines have evidence of intermittent drainage (McArthur, 1970). In September, 1981 a number of mines showed evidence of recent flow which is consistent with McArthur's observations. Impacts of these mines on surface water and groundwater obviously is variable in time and magnitude. Following periods of greater than normal precipitation, water resources impacts from mines is probably widespread in the Sand Coulee drainage. This type of problem obviously would be difficult to study and quantify.

BELT CREEK DRAINAGE

Coal was extensively mined in the vicinity of Belt in the early 1900's. There were several large mines and a few small mines. All mining was underground and the coal seam is in the upper portion of the Morrison Formation. Underground workings in the large mines were extensive and these workings encountered groundwater. The high content of pyrite in the coal has created acid mine drainage.

The community of Belt is located 12 miles east of Great Falls and it is adjacent to Belt Creek (Figure 8). Mining wastes consisting of carbonaceous shales, low grade coal and waste rock, are present along hillsides near the abandoned mines and they cover an extensive area along Belt Creek. Acid drainage from the mines flows down steep slopes to the drainage bottom and enters Belt Creek.

The drainage bottom along Belt Creek is 1500 to 2000 feet wide and is bordered by steep bluffs 200 to 300 feet in height. Numerous small drainages are tributary to Belt Creek and they originate in the rolling uplands east and west of Belt Creek. Elevations in the area range from about 3475 feet along the stream channel near Belt to over 3900 feet in the nearby uplands.

The Belt area was investigated to determine the location of abandoned coal mining operations and the existence and extent of acid mine discharge (AMD) from abandoned coal mines. To evaluate AMD and impacts to the environment, adits emitting AMD were examined, surficial geology was mapped, and water resources were investigated including surface water, groundwater and water quality. Land and water resources impacts of AMD in the drainage were determined.

GEOLOGY

There have been several investigations of geology in the Belt area including Fisher (1909) and Silverman and Harris (1967). The Belt

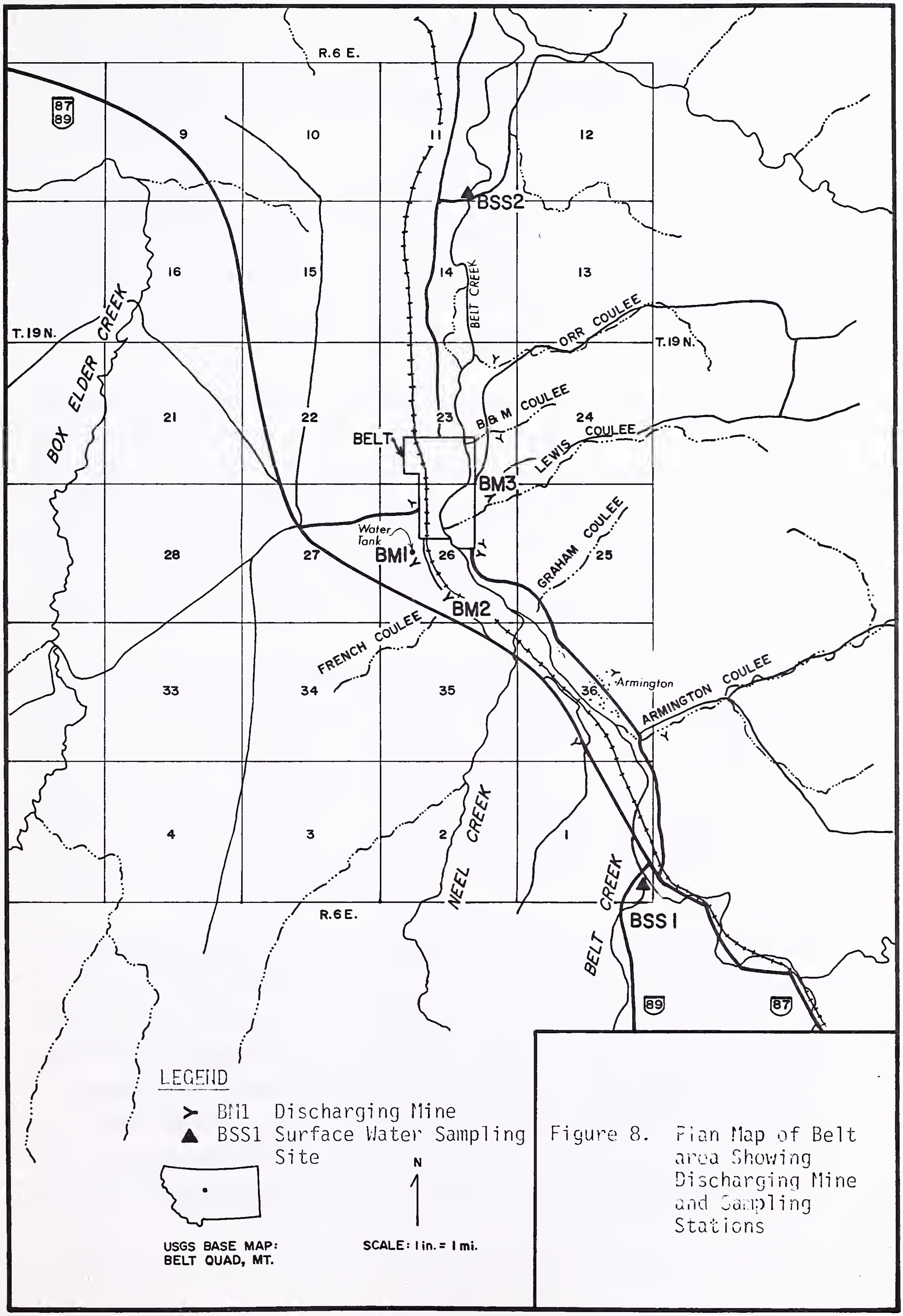


Figure 8. Plan Map of Belt area Showing Discharging Mine and Sampling Stations

area is part of the Great Falls-Lewistown Coal Field which is a large deposit of sub bituminous coal extending from Great Falls to Lewistown.

Geological formations of interest in the Belt area are the Kootenai Formation of Cretaceous geological age and the underlying Morrison Formation of Jurassic age. Unconsolidated alluvium is present along Belt Creek and also is important to the area's groundwater resources. Surficial geology of the Belt area is shown in Figure 9.

The Morrison Formation is exposed in bluffs along the drainage bottom. The Morrison consists of 50 to 250 feet of mudstone with interbedded lenses of limestone and sandstone. The lower and middle Morrison is predominantly mudstone with limestone beds as much as 10 feet thick and sandstone lenses as much as 35 feet thick (Silverman and Harris, 1967). The upper part of the Morrison is a carbonaceous shale containing coal seams and thin lenses of fine-grained sandstone.

Overlying the Morrison Formation is the Kootenai Formation. The Kootenai is 400 to 500 feet thick and consists of a basal sandstone overlain by red and maroon mudstones (Silverman and Harris, 1967) along the bluff. The exposed basal sandstone is thin to medium-bedded, flaggy and jointed. This sandstone weathers to form steep slopes and small cliffs. Entrances to coal mines in the Belt area are overlain by this sandstone.

The drainage bottom along Belt Creek is underlain by unconsolidated alluvium. This alluvium consists of layers, lenses and mixtures of gravel, sand, silt and clay. Thickness of the alluvium is poorly known but it probably is over 50 feet in most of the drainage bottom. As reported by Silverman and Harris (1967) coal in the Belt basin is in three benches with a total average thickness of 5 feet. The coal is sub bituminous B to high-volatile C. Coal in this area also has a high sulfur content and contains considerable pyrite.

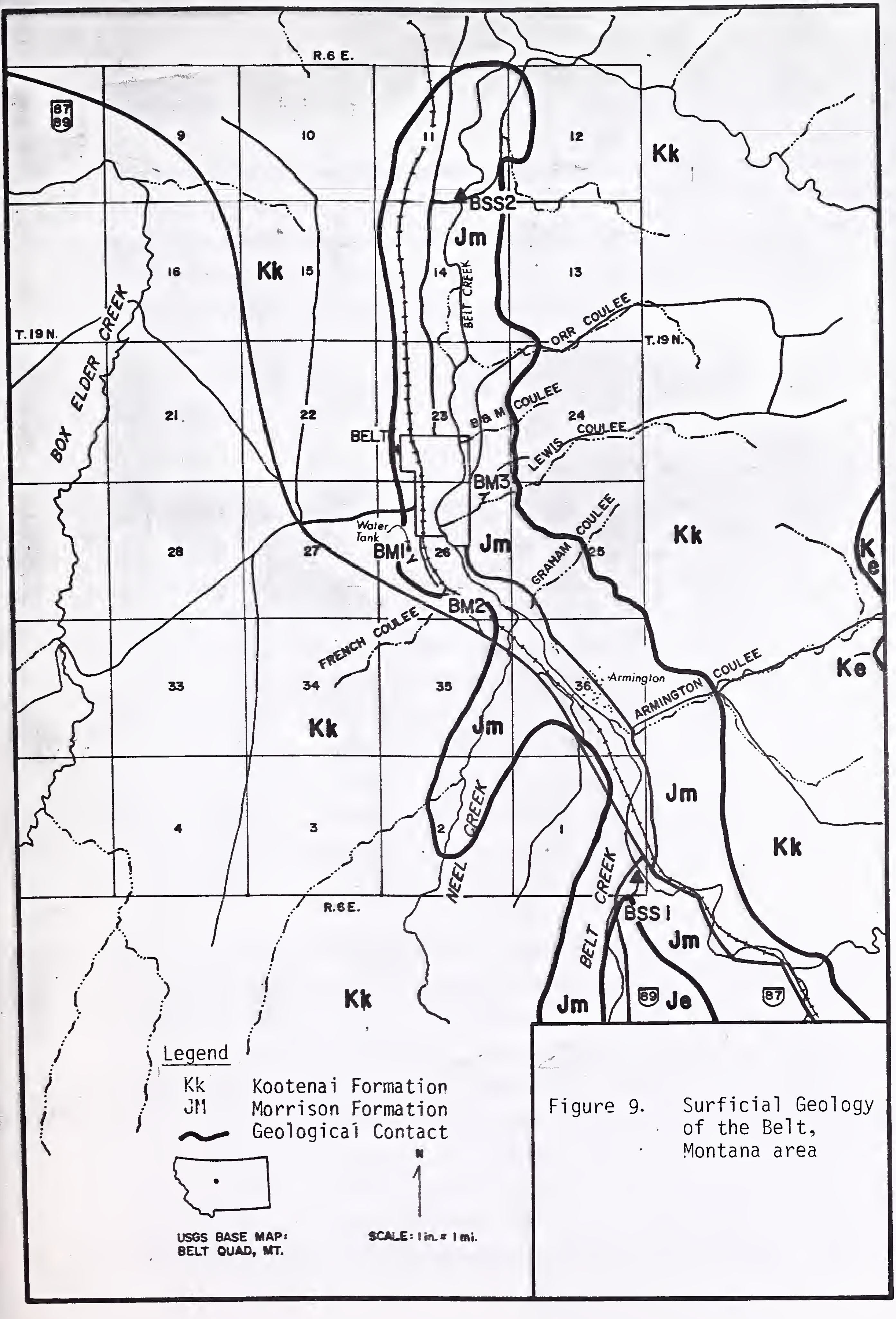


Figure 9. Surficial Geology of the Belt, Montana area

HYDROLOGY

The Belt area is drained by Belt Creek and its tributaries. Groundwater is present in the drainage in numerous formations and is widely used for stock, domestic and public water supply purposes. Acid drainage from the abandoned coal mines is limited to the immediate vicinity of Belt, Montana and has had impacts on both surface water and groundwater resources in the drainage.

Surface Water

Headwaters of Belt Creek are in the Little Belt Mountains southeast of Great Falls, Montana. Portions of the Little Belts drained by Belt Creek are highly mineralized and have been sites of mining activity since the 1800's. Flowing north to its junction with the Missouri River, Belt Creek is paralleled by U. S. Highway 89 for about half its length. Summer home and camp development along the stream, in the vicinity of Monarch, Montana, has been popular with Great Falls residents for many years. Belt Creek leaves the Little Belts and enters a narrow foothills valley at Riceville, Montana. The valley widens at Belt, Montana, but the general land relief remains moderate. Extensive coal deposits exist adjacent to Belt. They have been worked sporadically since 1876 and are the focus of this report.

Belt Creek has a drainage area of approximately 524 square miles and is considered a perennial stream although periods of no flow have been observed just above its confluence with Otter Creek (Figure 7) in years of low precipitation. Streamflows in the Belt Creek drainage are affected by local weather conditions, geology, and irrigation. A major share of the annual flow occurs during spring runoff. However, spring runoff is a function of weather and precipitation and may be quite variable in both time and volume of runoff. March through early July is the most common snowmelt period, but warm weather in mid-winter can produce significant streamflows for brief time periods. Peak flows

tend to occur from mid-May through June. The USGS has maintained a streamflow gaging station (Belt Creek near Monarch, Montana, 06090500) since 1951. Typical streamflow patterns for Belt Creek are shown in Figure 10. The USGS installed a crest gage on Little Otter Creek (06090550), a tributary of Belt Creek, in 1974. There are no other streamflow gaging stations in the drainage. Streamflow in Belt Creek was measured above Belt (Site BSS 1, Figure 8) and downstream from Belt (BSS 2, Figure 8). Flows on August 13, 1980 were 52 cfs and 39 cfs respectively. Belt creek is known to lose considerable water in its lower reaches due to infiltration into underlying geological materials. Fisher (1909) stated:

> It is a vigorous mountain stream, which carries a large flow of water in its upper course throughout all seasons of the year, especially near the mountains, but at the town of Belt all this water sinks to an underflow during the late summer months, leaving the stream bed dry. The loss is probably due to the fact that soft porous sandstone forms the floor of Belt Creek valley.

Water Quality

Belt Creek near Neihart has moderately hard, calcium-bicarbonate water with low sulfate, chloride, magnesium and sodium concentrations and low turbidity. Metal concentrations near the Neihard station generally were low, except during spring runoff. Significantly higher trace metal concentrations in the vicinity of Monarch were attributed to hard rock mining in the Carpenter Creek and Dry Fork of Belt Creek drainages (Braico and Botz, 1974).

The Belt Creek drainage to and including the Otter Creek drainage is classified B-1 by the Montana Surface Water Quality Standards, except for a small tributary near Neihart, Montana which serves as that community's water supply and therefore receives a higher water use classification. Streams classified B-1 are suitable for drinking, culinary and food processing purposes, after conventional treatment; bathing,

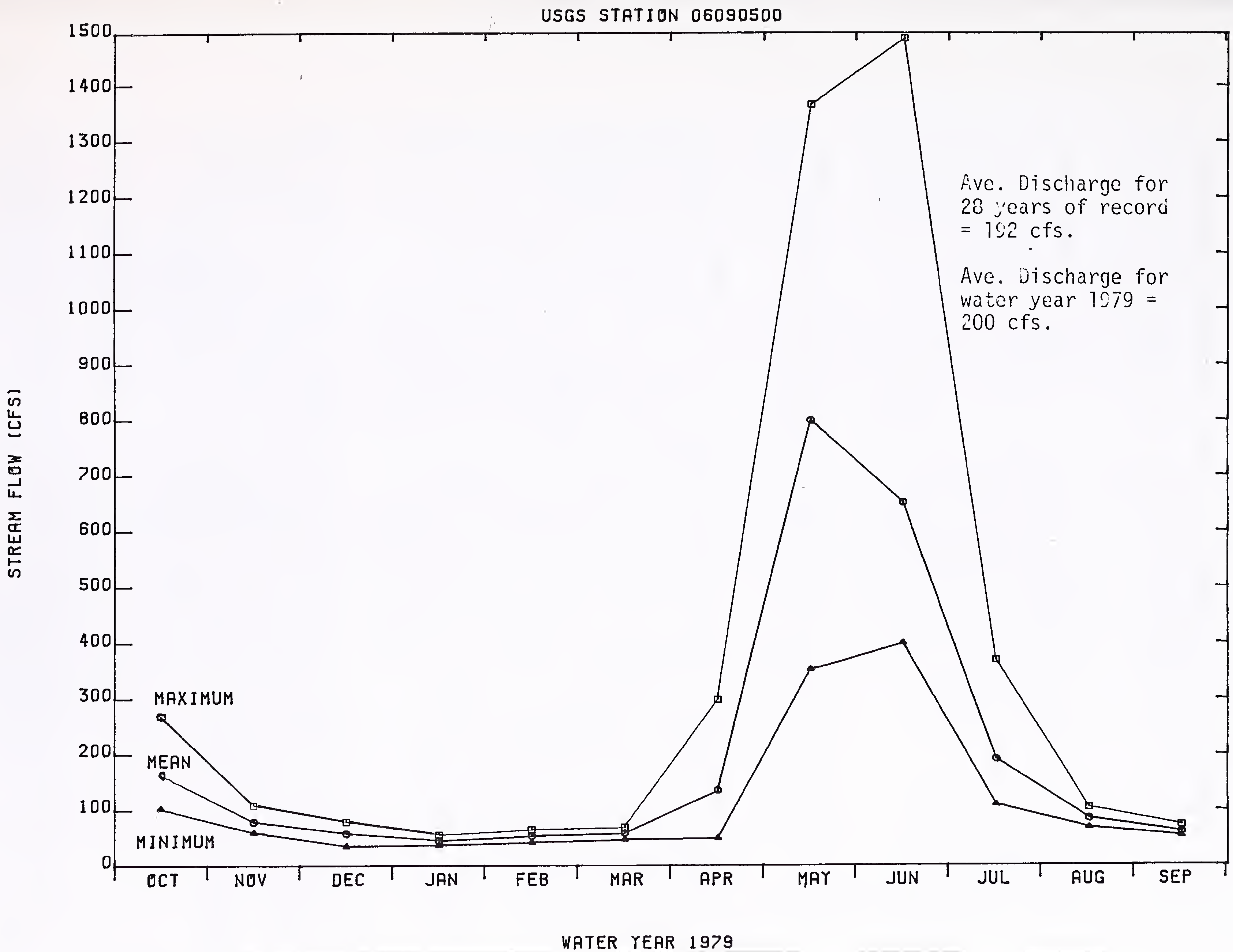


Figure 10. Streamflow Hydrograph for Belt Creek near Monarch, Montana

swimming and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.

The mainstem of Belt Creek from Otter Creek to the Missouri River is classified B-2. Streams classified B-2 are suitable for drinking, culinary and food processing purposes, after conventional treatment; bathing, swimming and recreation; growth and marginal propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.

Tributaries to Belt Creek from Otter Creek to the Missouri River are classified B-1 by the Montana Surface Water Quality Standards.

A limited number of water quality samples were collected for chemical analyses from Belt Creek above (BSS 1) and below (BSS 2) discharging coal mines in the vicinity of Belt, Montana (Table 14). Based on these samples a small increase in common cations and anions (e.g. calcium, magnesium, sodium, bicarbonates, sulfate) was indicated at the downstream station. Examination of metals indicates significant increases in iron and aliminum at the downstream station. Concentrations of other trace metals such as copper, chromium, cadmium, arsenic, mercury and zinc were unaffected by mine discharges. No pH measurements were less than 7.5 standard units at either station.

Belt Creek at both stations can be classified as hard to very hard,[1] non-saline, calcium-bicarbonate waters with typically low trace metals concentrations. Except for iron and manganese, Belt Creek at both stations meets Federal drinking water standards for public water supplies and recommended limits for livestock water.

Mine Effluent Discharge

Mine adits were located in the Belt, Montana area using recent aerial photographs and U. S. Geological Survey quadrangle maps. Most of these

TABLE 14 SUMMARY OF WATER QUALITY SAMPLING - BELT Surface Water

SAMPLING SITE	BSS1	BSS1	BSS1	BSS1	BSS2	BSS2	BSS2	BSS2	M BLW BELT CRK	M ABV BELT CRK
SAMPLE DATE	08/13/80	12/08/80	01/12/81	04/21/81	08/13/80	12/08/80	01/12/81	04/21/81	11/28/80	11/28/80
PHYSICAL PARAMETERS										
SPEC. COND. UMHOS/CM LAB	350	638	520	220	370	585	640	300	420	420
TURBIDITY (JTU) LAB	2.0	18		8.4	2.2	1.9		37	4.0	5.1
PH LAB	7.7	8.0	8.2	7.6	7.7	7.9	8.1	7.5	7.8	7.9
TOTAL SUSP. SOLIDS	2	3		35	3	2		118	25	20
TOTAL DISS. SOLIDS MEAS.	213	424		149	249	380		177	252	246
COMMON IONS										
CALCIUM (CA)	51	96		32	55	91		38	45	44
MAGNESIUM (MG)	15	24		10	16	21		12	16	15
SODIUM (NA)	4	8		9	4	7		11	19	20
POTASSIUM (K)	1	2		3	2	2		2	3	3
ACIDITY AS CACO3			0				0			
BICARBONATE (HCO3)	144	202		107	149	228		126	177	177
CARBONATE (CO3)	0	0		0	0	0		0	0	0
SULFATE (SO4)	69	183		32	97	135		50	70	65
CHLORIDE (CL)	1	10		10	1	10		1	11	11
FLUORIDE (F)	0.41	0.2		(0.10	0.17	0.17		0.12	0.68	0.72
NUTRIENTS										
AMMONIA (NH4-N)	(0.10			0.1	(0.10			0.3	(0.1	(0.10
NITRATE + NITRITE AS N	(0.05	0.08		(0.05	(0.05	0.05		0.06	0.23	0.25
TRACE METALS										
ARSENIC (AS) TOTAL	(0.005			(0.005	(0.005			(0.005		
ARSENIC (AS) DISS	(0.005				(0.005				0.014	0.016
ALUMINUM (AL) TOTAL	(0.1			0.4	0.2			2.3		
ALUMINUM (AL) DISS	(0.1				0.1				0.1	(0.1
CADMIUM (CD) TOTAL	(0.001			0.002	(0.001			0.001		
CADMIUM (CD) DISS	(0.001				(0.001				(0.001	(0.001
COPPER (CU) TOTAL	(0.01	(0.01		0.02	(0.01	(0.01		0.02		
COPPER (CU) DISS	(0.01	(0.01			(0.01	(0.01			(0.01	(0.01
CHROMIUM (CR) TOTAL	(0.02			(0.02	0.02			(0.02		
CHROMIUM (CR) DISS	(0.02				(0.02				(0.02	(0.02
IRON (FE) TOTAL	0.11	(0.03		0.60	0.54	0.20		1.94		
IRON (FE) DISS	0.09	(0.03			(0.03	0.17			0.18	0.18
LEAD (PB) TOTAL	(0.01			0.01	(0.01			0.02		
LEAD (PB) DISS	(0.01				(0.01				(0.01	(0.01
MANGANESE (MN) TOTAL	(0.02			0.11	0.04			0.26		
MANGANESE (MN) DISS	(0.02				0.04				0.03	0.03
MERCURY (HG) TOTAL	(0.001			(0.001	(0.001			(0.001		
MERCURY (HG) DISS	(0.001				(0.001				(0.001	(0.001
MOLYBDENUM (MO) TOTAL	(0.005			0.009	(0.005			0.023		
MOLYBDENUM (MO) DISS	(0.005				(0.005				(0.005	(0.005
NICKEL (NI) TOTAL	0.03			0.04	(0.03			0.05		

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 14 SUMMARY OF WATER QUALITY SAMPLING - BELT Surface Water

SAMPLING SITE	BSS1	BSS1	BSS1	BSS1	BSS2	BSS2	BSS2	BSS2	M BLW BELT CRK	M ABV BELT CRK
SAMPLE DATE	08/13/80	12/08/80	01/12/81	04/21/81	08/13/80	12/08/80	01/12/81	04/21/81	11/28/80	11/28/80
NICKEL (NI) DISS	<0.03				<0.03				0.07	0.05
SELENIUM (SE) TOTAL	<0.005			<0.005	<0.005			<0.005		
SELENIUM (SE) DISS	<0.005				<0.005				<0.005	<0.005
SILVER (AG) TOTAL	<0.005			<0.005	<0.005			<0.005		
SILVER (AG) DISS	<0.005				<0.005				<0.005	<0.005
ZINC (ZN) TOTAL	0.01	0.01		0.15	0.02	0.02		0.20		
ZINC (ZN) DISS	0.01	<0.01			0.01	<0.01			<0.01	0.02
OTHER PARAMETERS										
BORON (B)	<0.10	<0.10		<0.1	<0.10	<0.10		<0.1	0.13	0.15
SILICA (SIO2)	10.7			7.1	9.6			7.9	19.2	20.5

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

adits are shown on Figure 7. All of the adits were investigated during the summer of 1980 to determine the characteristics of the adits and existence of water discharges (Table 15). Three of the adits investigated were discharging effluent (Figure 7). It was apparent that discharges from these mines had occurred for many years. However, no prior study of the area had been made except for a general water resources inventory by Braico and Botz (1974).

Each of the adits were visited several times between August 1980 and July 1981. All of the adits were discharging continuously throughout the study period. However, flows were typically lowest during winter and early spring (Table 16). Water quality samples were collected for laboratory examination during each visit.

The large variations in discharge from mines BM-2 and BM-3 during the course of a year clearly illustrates the correlation between precipitation periods and increased flow coincident with the 35 day period of almost constant precipitation totaling over 6.10 inches beginning May 8, 1981, and ending June 18, 1981. The limited seasonal change in discharge from Mine BM 1 probably indicates that aquifers discharging this are of large areal extent and have relatively low transmissivities. Flow measurements made by DSL personnel in 1979 support these conclusions. In addition, low flow measurements made in 1979 correlate well with low flow measurements made during this study. At this time, information collected on the mine discharges does not clearly indicate a trend toward an increase or a decrease in mine effluent flows with time.

The overall quality of water discharging from coal mines in the Belt Creek drainage is poor. All the mines discharged waters with low pH, high specific electrical conductivity, and high concentrations of

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(1) Waters with a hardness range of 121-180 mg/l as $CaCO_3$ and greater than 180 mg/l as $CaCO_3$ were considered hard and very hard respectively.

TABLE 15. PHYSICAL CHARACTERISTICS OF COAL MINES NEAR BELT, MONTANA

Mine Number and Name	Location	Mine Size	Amount of Mine Waste Present	Extent Subsidence Areas	Mine Adit El. Ab. (MSL)	Resource Impacted
BM 1 Anaconda	19N06E26BDC	L	L	S	3650	SW Qual & Quan Esthetic Value
BM 2	19N06E26DCB	S	0	0	3560	SW Qual & Quan GW Quality
BM 3 Clone & Johnson	19N06E26AA	M	S	S	3570	SW Qual, GW Qual & Quan

Notes: All mines located in Cascade County, Montana
All elevations taken from USGS topographic map (Belt, Montana 15 minute quadrangles)
0 - none, S - small, M - medium, L - large
Qual - quality, Quan - quantity

TABLE 16. SUMMARY OF FLOW MEASUREMENTS FOR MINES
IN THE BELT CREEK DRAINAGE, MONTANA

(All Flows are in Gallons Per Minute)

			1981				1980		1979
Site	1/12	4/21	5/7	5/20	6/13	7/8	8/13	12/8	10/24
BM-1	92	165	165	165	166	161	145		80
BM-2	5	14	11	25	71	45	12		15
BM-3	3 est.	56	20	200 est.	150 est.	55	7		7.5

1979 data from Montana Department of State Lands. Remaining data collected by Hydrometrics.

sulfate, acidity, and metals, particularly iron and zinc (Table 17). The general quality of water from the four discharging mines sampled during low flow is outlined in Table 18. From this table it is apparent that mine BM 1 contributes nearly 80 percent of the total pollutant load to the stream system during low flow periods. Pollutant load is defined as the product of flow in gpm and specific electrical conductivity in μmhos/cm at 25°C. This "load factor" gives a comparative indication of water quality impacts from the mines.

The quantity of water discharged from mines BM 1, BM 2 and BM 3 varies widely. Therefore, the relative contribution of pollutants from these mines probably is similarly variable. Precipitation obviously has a significant influence on discharge from most mines. The wide variability in flow, water quality and pollutant loads creates a most difficult problem to solve.

As shown in Table 18, all mine effluents had a specific electrical conductivity of from 1900 to 6800 μmhos/cm with water discharged from BM 2 being of significantly poorer quality than the other mine waters. Mine effluents from BM 1, BM 2 and BM 3 can be characterized as very acidic, magnesium-calcium-sulfate type waters with high concentrations of dissolved solids and metals. None of these waters meet federal primary and secondary drinking water standards. Due to high acidity, and high concentrations of total dissolved solids and metals, the mine effluents also are unsuitable for irrigation and livestock use.

TABLE 17 SUMMARY OF WATER QUALITY SAMPLING - BELT Mine Discharge

SAMPLING SITE	BM1	BM1	BM1	BM1	BM1
SAMPLE DATE	08/13/80	12/08/80	01/12/81	04/20/81	04/21/81
PHYSICAL PARAMETERS					
FLOW (GPM)	145		92	165	
WATER TEMPERATURE (C)				10	
SPEC. COND. UMHOS/CM FIELD				2300	
SPEC. COND. UMHOS/CM LAB	2250	2590	2400		1900
TURBIDITY (JTU) LAB		5.0			
PH FIELD				2.7	
PH LAB	2.8	2.8	2.6		2.6
TOTAL SUSP. SOLIDS		12			
TOTAL DISS. SOLIDS MEAS.	2060	2230			1540
COMMON IONS					
CALCIUM (CA)	155	162			130
MAGNESIUM (MG)	68	72			59
SODIUM (NA)	11	12			26
POTASSIUM (K)	3	3			4
ACIDITY AS CACO3	1140	1310	1090		729
BICARBONATE (HCO3)	0	0			0
CARBONATE (CO3)	0	0			0
SULFATE (SO4)	1750	1950			1320
CHLORIDE (CL)	70	30			2
FLUORIDE (F)	<0.1	1.24			1.03
NUTRIENTS					
AMMONIA (NH4-N)	0.56				0.4
NITRATE + NITRITE AS N	0.21	<0.05			0.40
TRACE METALS					
ARSENIC (AS) TOTAL					0.035
ARSENIC (AS) DISS	0.042				
ALUMINUM (AL) TOTAL					61
ALUMINUM (AL) DISS	80				
CADMIUM (CD) TOTAL					0.009
CADMIUM (CD) DISS	0.007				
COPPER (CU) TOTAL					0.06
COPPER (CU) DISS	0.04	0.03			
CHROMIUM (CR) TOTAL					0.03
CHROMIUM (CR) DISS	0.07				
IRON (FE) TOTAL					148
IRON (FE) DISS	210	454			
LEAD (PB) TOTAL					0.01
LEAD (PB) DISS	0.02				
MANGANESE (MN) TOTAL					0.35
MANGANESE (MN) DISS	0.47				
MERCURY (HG) TOTAL					<0.001

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 17 SUMMARY OF WATER QUALITY SAMPLING - BELT Mine Discharge

SAMPLING SITE	BM1	BM1	BM1	BM1	BM1
SAMPLE DATE	08/13/80	12/08/80	01/12/81	04/20/81	04/21/81
MERCURY (HG) DISS	<0.001				
MOLYBDENUM (MO) TOTAL					0.032
MOLYBDENUM (MO) DISS	<0.005				
NICKEL (NI) TOTAL					0.85
NICKEL (NI) DISS	0.96				
SELENIUM (SE) TOTAL					<0.005
SELENIUM (SE) DISS	<0.005				
SILVER (AG) TOTAL					<0.005
SILVER (AG) DISS	<0.005				
ZINC (ZN) TOTAL					3.44
ZINC (ZN) DISS	3.96	3.9			
OTHER PARAMETERS					
BORON (B)	<0.05	0.39			<0.1
SILICA (SIO2)	85.6				60
LOAD FACTOR	32.6		22.1		

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 17 SUMMARY OF WATER QUALITY SAMPLING - BELT Mine Discharge

SAMPLING SITE	BM2	BM2	BM2	BM2	BM2
SAMPLE DATE	08/13/80	12/08/80	01/12/81	04/20/81	04/21/81
PHYSICAL PARAMETERS					
FLOW (GPM)	12		5	14	
WATER TEMPERATURE (C)				11	
SPEC. COND. UMHOS/CM FIELD				5908	
SPEC. COND. UMHOS/CM LAB	5200	6800	6600		5500
TURBIDITY (JTU) LAB		26			
PH FIELD				2.35	
PH LAB	2.6	2.6	2.5		2.3
TOTAL SUSP. SOLIDS		6			
TOTAL DISS. SOLIDS MEAS.	5820	8760			6420
COMMON IONS					
CALCIUM (CA)	266	296			220
MAGNESIUM (MG)	120	160			124
SODIUM (NA)	12	19			25
POTASSIUM (K)	7	9			7
ACIDITY AS CACO3	5000	6120	7290		4882
BICARBONATE (HCO3)	0	0			0
CARBONATE (CO3)	0	0			0
SULFATE (SO4)	5360	8240			6040
CHLORIDE (CL)	57	32			8
FLUORIDE (F)	<0.1	0.15			0.17
NUTRIENTS					
AMMONIA (NH4-N)	0.32				0.4
NITRATE + NITRITE AS N	<0.05	<0.01			0.17
TRACE METALS					
ARSENIC (AS) TOTAL					0.12
ARSENIC (AS) DISS	0.21				
ALUMINUM (AL) TOTAL					370
ALUMINUM (AL) DISS	413				
CADMIUM (CD) TOTAL					0.009
CADMIUM (CD) DISS	0.010				
COPPER (CU) TOTAL					0.16
COPPER (CU) DISS	0.09	0.12			
CHROMIUM (CR) TOTAL					0.18
CHROMIUM (CR) DISS	0.19				
IRON (FE) TOTAL					925
IRON (FE) DISS	1110	1388			
LEAD (PB) TOTAL					<0.01
LEAD (PB) DISS	0.07				
MANGANESE (MN) TOTAL					0.89
MANGANESE (MN) DISS	0.93				
MERCURY (HG) TOTAL					<0.001

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 17 SUMMARY OF WATER QUALITY SAMPLING - BELT Mine Discharge

SAMPLING SITE	BM2	BM2	BM2	BM2	BM2
SAMPLE DATE	08/13/80	12/08/80	01/12/81	04/20/81	04/21/81
MERCURY (HG) DISS	<0.001				
MOLYBDENUM (MO) TOTAL					0.045
MOLYBDENUM (MO) DISS	<0.005				
NICKEL (NI) TOTAL					1.02
NICKEL (NI) DISS	1.23				
SELENIUM (SE) TOTAL					<0.005
SELENIUM (SE) DISS	0.007				
SILVER (AG) TOTAL					<0.005
SILVER (AG) DISS	<0.005				
ZINC (ZN) TOTAL					4.47
ZINC (ZN) DISS	3.74	6.5			
OTHER PARAMETERS					
BORON (B)	0.53	1.42			<0.1
SILICA (SIO2)	104.7				120
LOAD FACTOR	6.2		3.3		

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 17 SUMMARY OF WATER QUALITY SAMPLING - BELT Mine Discharge

SAMPLING SITE	BM-2A
SAMPLE DATE	01/27/82
PHYSICAL PARAMETERS	
SPEC. COND. UMHOS/CM LAB	2390
PH LAB	2.2
TOTAL DISS. SOLIDS MEAS.	2300
COMMON IONS	
TOTAL HARDNESS AS CACO3	488
CALCIUM (CA)	108
MAGNESIUM (MG)	53
SODIUM (NA)	8
POTASSIUM (K)	3
ACIDITY AS CACO3	1360
BICARBONATE (HCO3)	0
CARBONATE (CO3)	0
SULFATE (SO4)	1670
CHLORIDE (CL)	4
FLUORIDE (F)	0.1
NUTRIENTS	
AMMONIA (NH4-N)	0.1
NITRATE (NO3-N)	<0.05
TRACE METALS	
ARSENIC (AS) TOTAL	0.043
ALUMINUM (AL) TOTAL	94
CADMIUM (CD) TOTAL	0.012
COPPER (CU) TOTAL	0.02
CHROMIUM (CR) TOTAL	0.05
IRON (FE) TOTAL	204
LEAD (PB) TOTAL	0.01
MANGANESE (MN) TOTAL	0.22
MERCURY (HG) TOTAL	<0.0002
MOLYBDENUM (MO) TOTAL	0.015
NICKEL (NI) TOTAL	0.43
SELENIUM (SE) TOTAL	<0.005
SILVER (AG) TOTAL	<0.005
ZINC (ZN) TOTAL	1.86
OTHER PARAMETERS	
BORON (B)	0.2
SILICA (SIO2)	69

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 17 SUMMARY OF WATER QUALITY SAMPLING - BELT Mine Discharge

SAMPLING SITE	BM3	BM3	BM3	BM3	BM3
SAMPLE DATE	08/13/80	12/08/80	01/12/81	04/20/81	04/21/81
PHYSICAL PARAMETERS					
FLOW (GPM)	7		5	56	
WATER TEMPERATURE (C)				10	
SPEC. COND. UMHOS/CM FIELD				4267	
SPEC. COND. UMHOS/CM LAB	3400	3820	4000		4000
TURBIDITY (JTU) LAB		4.2			
PH FIELD				2.45	
PH LAB	2.8	2.8	2.6		2.5
TOTAL SUSP. SOLIDS		64			
TOTAL DISS. SOLIDS MEAS.	3320	4150			4070
COMMON IONS					
CALCIUM (CA)	149	157			153
MAGNESIUM (MG)	113	119			114
SODIUM (NA)	38	36			40
POTASSIUM (K)	3	3			5
ACIDITY AS CACO3	2550	2630	3200		2470
BICARBONATE (HCO3)	0	0			0
CARBONATE (CO3)	0	0			0
SULFATE (SO4)	2940	3810			3750
CHLORIDE (CL)	73	24			10
FLUORIDE (F)	<0.1	0.10			0.22
NUTRIENTS					
AMMONIA (NH4-N)	0.82				0.5
NITRATE + NITRITE AS N	<0.05	<0.05			0.14
TRACE METALS					
ARSENIC (AS) TOTAL					0.144
ARSENIC (AS) DISS	0.070				
ALUMINUM (AL) TOTAL					230
ALUMINUM (AL) DISS	203				
CADMIUM (CD) TOTAL					0.051
CADMIUM (CD) DISS	0.042				
COPPER (CU) TOTAL					0.14
COPPER (CU) DISS	0.08	0.09			
CHROMIUM (CR) TOTAL					0.16
CHROMIUM (CR) DISS	0.15				
IRON (FE) TOTAL					540
IRON (FE) DISS	480	420			
LEAD (PB) TOTAL					<0.01
LEAD (PB) DISS	0.03				
MANGANESE (MN) TOTAL					1.21
MANGANESE (MN) DISS	1.07				
MERCURY (HG) TOTAL					<0.001

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 17 SUMMARY OF WATER QUALITY SAMPLING - BELT Mine Discharge

SAMPLING SITE	BM3	BM3	BM3	BM3	BM3
SAMPLE DATE	08/13/80	12/08/80	01/12/81	04/20/81	04/21/81
MERCURY (HG) DISS	<0.001				
MOLYBDENUM (MO) TOTAL					0.048
MOLYBDENUM (MO) DISS	0.008				
NICKEL (NI) TOTAL					2.29
NICKEL (NI) DISS	2.36				
SELENIUM (SE) TOTAL					<0.005
SELENIUM (SE) DISS	<0.005				
SILVER (AG) TOTAL					<0.005
SILVER (AG) DISS	<0.005				
ZINC (ZN) TOTAL					8.54
ZINC (ZN) DISS	8.44	9.2			
OTHER PARAMETERS					
BORON (B)	0.26	0.56			<0.1
SILICA (SIO2)	107.0				74
LOAD FACTOR	2.4		2.0		

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED

TABLE 18. WATER QUALITY CHARACTERISTICS OF COAL MINES IN THE BELT CREEK DRAINAGE

Mine Number and Name	Location	Receiving Stream	Water Quality Sample Taken	Mine Effluent Quality	pH	S.C. @ $25^{\circ}C$ (μmhos/cm)	Effluent Discharge (gpm)	Load Factor x 10^4	Percent Relative Load Contribution
BM 1	19N06E26BDC	Belt Creek	yes	poor	2.8	2250	145	32.6	79
BM 2	19N06E26DCB	Belt Creek	yes	poor	2.6	5200	12	6.2	15
BM 3	19N06E26AA	Belt Creek	yes	poor	2.8	3400	7	2.4	6
									100

Notes: Data based on Hydrometrics August 1980 samples for mines BM 1, BM 2 and BM 3.
S.C. is specific electrical conductivity at $25^{\circ}C$.
(gpm) is gallons per minute
S.C. x gpm = loading factor
See Exhibit 2 for location of mine adits.

TABLE 19. MINE ADIT DESCRIPTIONS OF DISCHARGING MINES NEAR BELT, MONTANA

Descriptive Terms	BM 1 (7-5)	BM 2 (7-5)	BM 3 (7-24)
Adit Condition	Partially caved	Completely caved	Partially covered
Roof Materials	Fractured sandstone	Earthen materials	Fractured sandstone
Sidewall Materials	Friable, shale-like, coal	Unknown	Friable, shale-like coal
Floor Materials	Covered w/debris	Unknown	Debris from side walls
Timbers Present	Exposed 20' into mine	None	Partially covered timbers from old structure
Debris Present	Partially covering floor and front of adit	Completely covered	Some covering old floor and front of adit
Width (ft)	20	10	5
Height (ft)	3	Unknown	5
Height of Material above adit (ft)	60		40 ft of sandstone
Extent of Water Present	Water upwells from ground down below adit	Water seeps out of ground below mine	Small amount seeps out of base of adit
Length of Opening of Adit	20	None	50
Coal seam thickness	Unknown	Unknown	5

Note: Montana DSL mine designations shown in parenthesis after the Hydrometrics designation.

Quality of water from BM 1 has been measured several times (Table 17). The mine discharge is very poor quality with low pH (2.6 to 2.8), high specific conductance (1900 to 2590 µmhos/cm), high acidity (729 to 1310 mg/l) and high sulfate (1320 to 1950 mg/l). Metal concentrations, particularly arsenic, aluminum, iron and manganese are high.

Mine BM 2

This abandoned mine is located about one mile south of Belt and is on a steep sidehill on the west side of Belt Creek. The BM 2 adit is completely caved and water exits through a small pipe and runs down a small ditch about 50 feet below a road. The water continues down the hillside to join Belt Creek.

Flow from BM 2 has varied widely (5 to 71 gpm, Table 16) reflecting the influence of precipitation in May and June 1981. Flows rapidly increased, peaked, then rapidly declined showing the good hydraulic contact between the mine and the overlying Kootenai Formation.

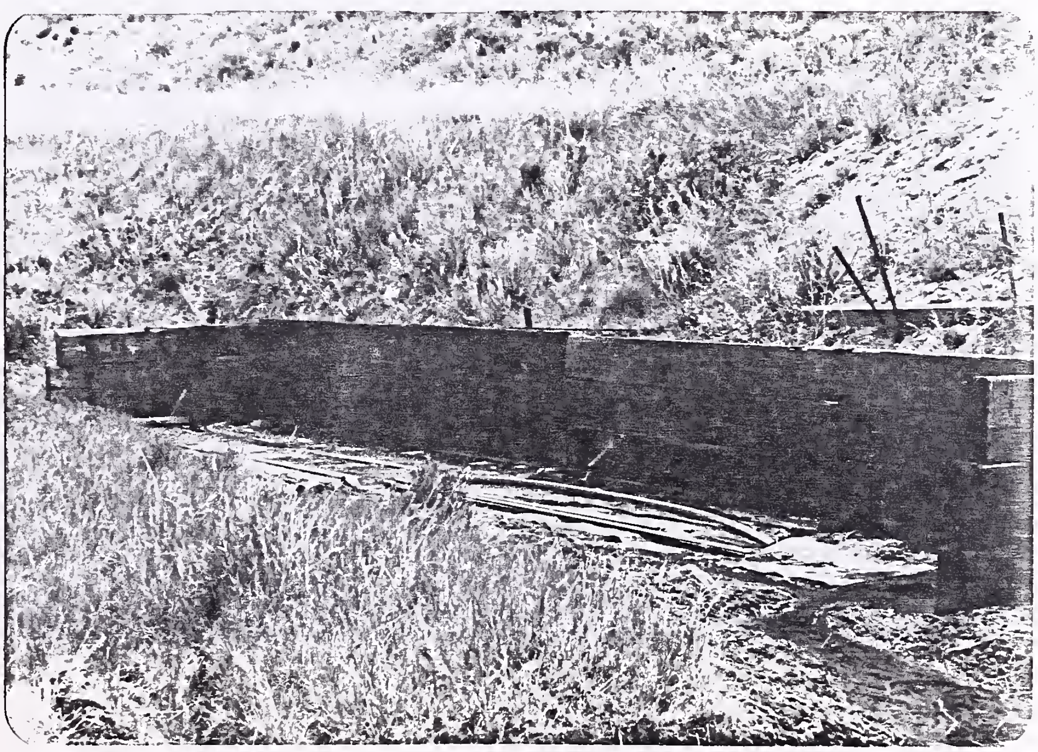
BM 2 - Mine Portal

Quality of effluent from BM 2 (Table 17) is very poor. Very low pH, high concentrations of acidity, sulfate and dissolved solids and metals make this water much poorer in quality than BM 1.

An additional source of acid mine discharge, termed BM 2A, is approximately one quarter mile southeast of BM 2. Water is discharging through three 2 inch diameter pipes protruding from wooden cribbing erected on the side hill above Belt creek. From this point, the discharge runs down a small ditch into a storm water/irrigation channel which joins Belt Creek.

There is no adit in the vicinity of the BM 2A discharge. It is possible that the discharge from this site originates from the same underground workings as those associated with BM 2. Another possibility is that the adit associated with the BM 2A discharge was covered by the roadfill used in the construction of U. S. Highway 87, which is located immediately above the point of discharge. Discussions with local residents provided no information on the history or source of the BM 2A discharge.

The volume of discharge was estimated at 3 gallons per minute on January 27, 1982. A sample of the discharge taken on that date showed the water quality of the effluent to be poor (Table 17). The discharge displays characteristics typical of acid mine drainage such as low pH and high concentrations of sulfate and iron.



BM 2A - Discharge Site

Mine BM 3

This mine is located directly east of Belt on a steep sidehill. Mine wastes are spread along the hillside and mine effluent exits the partially collapsed portal. Water cascades down a hillside in a small ditch and enters a small drainage. The water in this drainage joints water from Lewis Coulee and is transported through Belt in a small ditch to Belt Creek. The ditches are in poor condition, are not of sufficient capacity to handle large flows and are iron encrusted.

Flow from BM 3 (Table 16) shows a great fluctuation and ranged from 3 gpm on January 12, 1981 to over 200 gpm on June 20, 1981. This flow reflected the heavy precipitation in May and June 1981. The mine workings obviously are hydraulically connected to the overlying Kootenai Formation. There is a possibility that flow down Lewis Coulee (located just north of BM 3) caused increased flow in the mine workings either by a direct connection or by infiltration into the Kootenai Formation.

Quality of acid mine drainage from BM 3 is very poor. The AMD characteristics of low pH, and high concentrations of acidity, sulfate, dissolved solids and metals are present in this water (Table 17).

BM 3 - Mine Portal

IMPACTS OF AMD

Acid mine drainage has caused impacts to both land and water resources in the Belt area. Land impacts involve loss of vegetation along streams and ditches carrying AMD. Water resources impacts involve degradation of water quality in Belt Creek. The magnitude of degradation is dependent on the relationship of flow of AMD and flow in the receiving stream. At low flows in Belt Creek, in late summer through winter, AMD can have a very significant impact on water quality.

Specific water quality impacts are increased concentrations of dissolved and suspended solids, sulfate, metals and decreases in pH and alkalinity. During low flows in Belt Creek, AMD may cause the stream waters to be unfit for domestic, livestock or irrigation use and the aquatic communities are essentially destroyed. This impact can extend down Belt Creek to the Missouri River.

Groundwater also can be impacted both in quality and in quantity by AMD. Acid drainage in streams percolates into the subsurface and joins the existing groundwater system. This can increase groundwater flows, which in itself may not be harmful; however, the acid drainage is very poor in quality and normally would cause substantial degradation in groundwater quality.

Another adverse impact caused by acid mine drainage is one of aesthetic values in stream channels. The small channels carrying AMD are covered with a thick precipitate of iron and the water is discolored and turbid. This creates an unsightly condition.

There are no quantitative criteria for assessing overall resources impacts of mine drainage, however each discharging mine was evaluated and semi-quantitatively ranked relative to damage to land and water resources. This ranking provides a ready comparison of environmental impacts of each of the discharging mines in the Sand Coulee drainage (Table 20).

TABLE 20. HYDROLOGICAL IMPACTS OF ABANDONED COAL MINES ON RESOURCES NEAR BELT, MONTANA

Mine Number	S.W. Quality	S.W. Quantity	G.W. Quality	G.W. Quantity	Esthetic Value	Total Impact*
BM 1	L	M	S	S	M	1
BM 2	M	S	S	S	S	3
BM 3	M	S	S	S	S	2

Notes: S.W. is Surface Water, G.W. is Groundwater
Agri. Lands is Agricultural Lands
O - None L - Large
S - Small V - Variable
M - Moderate U - Unknown

* Total impacts is a semi-quantitative summation of impacts and gives the relative overall ranking of the impact of each mine.

Specific Mine Impacts

An evaluation was made of specific resource impacts from AMD from the three discharging mines in the Belt area. Effluent from BM 1 cascades down a steep slope and vegetation along this path is destroyed. The effluent reaches a small channel that is essentially an AMD ditch. This ditch conveys the effluent to Belt Creek. As previously described, the impacts on Belt Creek are a function of flow in the creek and effluent flow. Surface water degradation obviously will occur.

BM 2 and BM 3 have similar but lesser impacts than BM 1. These two mines also discharge to Belt Creek but flow from BM 2 and BM 3 is much less than from BM 1. The overall impact of these discharging mines is small sections of channels and ditches that are polluted and encrusted with precipitates and the water quality impact on Belt Creek and its aquatic community.

The existence of polluted surface waters also suggests that groundwater underlying these streams also is impacted. This impact depends on the relative proportion of natural groundwater and infiltration of polluted water into the groundwater system. The overall impact of groundwater quality probably is small.

METHODS FOR AMD CONTROL

A great deal of technical effort has been directed at control of acid mine drainage from abandoned coal mines in the United States. Much of this work has been conducted through funding from the Environmental Protection Agency (EPA) and the principle focus has been on mine drainage in the eastern portion of the United States. A large variety of acid mine drainage abatement and control techniques have been developed. These include a wide number of conventional and unconventional techniques for abating or elimination of acid mine drainage. The EPA (1973, 1975) described a number of methods and procedures to control mining activities. The Federal Water Quality Administration (1970) describes mine treatment techniques for water pollution abatement. EPA (1974 and 1976) describe analyses of pollution control costs and resource allocation to optimize pollution control. A large number of studies have been conducted and a wide variety of techniques utilized in acid mine drainage control including neutralization processes (EPA 1973) electrochemical treatment (EPA, 1972), flooding (EPA 1977), removal of metals by precipitation (EPA 1973), reverse osmosis (EPA 1973), cation removal (West Virginia University, 1976), use of limestone and packed tumbling drums for acidity reduction (Pearson and McDonnell, 1978).

Although a large number of innovative and technically sophisticated techniques have been developed for control of acid mine drainage, the application of these techniques to specific acid mine drainage problems has met with mixed success. Many acid mine drainage problems are simply uneconomical to treat and no cost effective solutions are available.

All techniques considered for control of acid mine drainage can be divided into three basic categories. These are:

1) Effluent Control
2) Mine Manipulation
3) Infiltration Control

A review of a large number of potential control or abatement techniques was made to determine their applicability to the Sand Coulee and Belt Mine drainages. Many techniques obviously are unsuitable, would have costs that are prohibitive or physically would not work in the environment at Sand Coulee or Belt. Of all the many techniques reviewed (Table 21), the techniques listed on Table 22 were selected for potential application in control of mine effluent problems in Sand Coulee and Belt.

Effluent Control

Probably the most common technique for treating acid drainage is treatment or control of effluent. Effluent control would include evaporation ponding, dilution in a stream or mixing with other waters for dilution and pH control. The objective of effluent control techniques is to improve the effluent quality so it can have a beneficial use.

By far the most common method for treatment of effluent is the use of limestone or lime to reduce acidity and precipitate metals. Other treatment techniques are separation of dissolved pollutants (metals and salts) from water. This can be accomplished by a wide variety of techniques including chemical precipitation, distillation, ion exchange and reverse osmosis. All these techniques depend on a chemical or physical treatment of the effluent to remove selected dissolved constituents. This process normally creates a sludge that is separated from the treated effluent.

Other widely used techniques for effluent control are ponding of effluent to allow seasonal evaporation, ponding of effluent and mixing with higher quality waters. This also adds oxygen to the system which may be beneficial in precipitation of dissolved metals. Effluent also can be diluted by regulation of streamflow using water released from impoundments or by supplementing streamflow by groundwater or water imported from other basins.

TABLE 21. LIST OF POTENTIAL ABATEMENT OR CORRECTIVE TECHNIQUES FOR MINES IN THE SAND COULEE AND BELT AREAS

EFFLUENT TREATMENT

- Reverse Osmosis
- Ion Exchange
- Electrodialysis
- Evaporation Ponds
- Neutralization
- Streamflow Regulation
- Permanganate Iron Removal
- Ozone Iron Removal
- Sulfide Iron Removal
- Microbiological Iron and Sulfur Removal
- Disposal in Deep Wells
- Disposal in Abandoned Mines
- Disposal in Streams at High water
- Mineral Recovery
- Electrochemical Removal of Heavy Metals
- Activated Carbon Filtering
- Freezing
- Foam Fractionation
- Bacteria Addition to System (iron oxidizing)
- Spray Irrigation
- Rerouting
- Subsurface Waste Injection

MINE MANIPULATION

- Dam and Flood Mine
- Backfill Mine With Waste
- Removal of Bacteria from Mine
- Divert Surface Runoff
- Single Bulkhead Seal
- Permeable Limestone Seal
- Gunite Seal
- Grout Curtain
- Double Bulkhead Seal
- Clay Seal
- Grout Bag Seal
- Regulated Flow Seal
- Dry Seal
- Subsidence Sealing
- Air Seal
- Gel Seal
- Hydraulic Seal

HYDROLOGIC SYSTEM CONTROL

- Pump Wells to Remove Water in Overburden
- Deep Well Neutralization
- Pump Wells in Mine Workings
- Soil Amendments
- Underdrains
- Vegetative Control of Infiltration
- Land Surface Sealing

TABLE 22. POTENTIAL AMD ABATEMENT OR CONTROL TECHNIQUES APPLICABLE TO MINES IN THE SAND COULEE AND BELT DRAINAGES

EFFLUENT CONTROL	
Streamflow Regulation	Neutralization
Evaporation Ponds	
MINE MANIPULATION	
Dam and Flooding	Hydraulic Seal
Seal Using Mine Backfill	
INFILTRATION CONTROL	
Overburden Water Removal by Wells	Vegetative Evapotranspiration

Mine Manipulation

Another major technique in controlling acid mine water is to alter the mine workings themselves to reduce the flow of effluent or to improve the quality of effluent that flows from the mine. This commonly is accomplished by flooding the mines with water to exclude oxygen, thereby reducing the rate of formation of acid drainage or by filling the mine with other materials that reduce the rate of reaction and the accessibility of oxygen and water to oxidizing pyritic material. Potential mine manipulation techniques for the Sand Coulee and Belt drainage are:

1) Construction of dams in coulees and flooding of the mines;
2) Sealing the mine portal to eliminate or reduce the effluent flow;
3) Backfilling the underground workings with waste material to reduce contact with oxygen and pyritic material and reduce effluent flow.

Infiltration Control

This technique has been used successfully in some mine drainage problems. The objective is control of infiltration into the mine workings by modification of the land surface above the mine. Specific techniques that have been used are creation of a relatively impermeable layer, utilization of water consuming plants, sloping the land surface to increase surface runoff or rerouting drainages to avoid concentration of water on the land surface above the mine. Another technique that has been used for infiltration control is removal of groundwater from the aquifer supplying water to the mine by means of wells or infiltration systems. All these techniques reduce the amount of water entering the mine workings and reduce the quantity of water exiting the mine.

FEASIBILITY OF AMD CONTROL

The mine drainage abatement or control methods outlined in this report (Methods for AMD Control section and Table 22) incorporate state-of-the-art principles applicable to the mines in the Sand Coulee and Belt drainages. The mine manipulation and infiltration control techniques are at-source abatement methods. They involve prevention of or reduction in the formation of pollutants, while the effluent control techniques involve treatment of acid drainage. Selection of an appropriate control method depends on desired results, capital costs of the method, operation and maintenance requirements and costs, environmental impacts, and potential risks associated with the method. At-source controls are designed to provide long-term reductions in formation of AMD. Effluent treatment methods are designed to achieve a water quality goal and normally require continued operation and maintenance efforts to achieve the desired result.

No goals or criteria for success have been developed for the Sand Coulee and Belt AMD problems nor is it easy to do so. Streams affected by AMD in the Sand Coulee Creek drainage are intermittent or ephemeral and probably could not support a fishery if AMD were eliminated. The AMD affected streams are not used for drinking water or irrigation. It is very doubtful that these streams in the future will be useful or needed as sources of domestic or public water. If AMD were abated, the stream could possibly be used for irrigation particularly if water storage facilities were constructed in the drainage. Abatement of AMD probably would improve the appearance of affected streams.

In the Belt area, Belt Creek supports a fishery and abatement of AMD would improve water quality and probably would result in a healthier aquatic community and an improved fishery. At low flows particularly, AMD abatement would be of significant in-stream value. Improvement of water quality also would improve the appearance of channels impacted by AMD.

Of the control techniques considered for the Sand Coulee and Belt area, five are at-source control and three are effluent treatment techniques. A general summary of control techniques for specific discharging mines is in Table 23. In this section, each potential control method is considered including its applicability, costs, benefits and impacts.

Streamflow Regulation

In the Sand Coulee Creek drainage a potential technique for improving water quality would be storage of water in holding ponds or reservoirs and release of stored water during the low flow season. The effect of this would be dilution of mine waters during the low flow season when streams are significantly affected by acid drainage. These reservoirs could be multiple purpose and could include recreation, flood control and irrigation benefits to the drainage.

The Soil Conservation Service in Montana has examined six dam sites in the Sand Coulee drainage (J. Schaefer, SCS. pers. comm., Sept. 1981). The purpose of these dams would be to control runoff and prevent flooding in the lower segments of the drainage. Dam sites were considered on upper Sand Coulee, Centerville, Antelope Coulee, Cottonwood Creek, lower Sand Coulee Creek, and Number Five Coulee. Storage in these dams ranged from 960 acre feet (af) to 7100 af. With storage of this magnitude the dams would have potential for providing some regulation of streamflow in the drainage. It is highly doubtful, however, that such dams could be economically justified on the basis of AMD control in streams. Costs of these dams were not estimated and the cost-effectiveness for correction of AMD cannot be determined. If future dams are considered for the drainage, then streamflow regulations should be considered as one of the potential uses and benefits of the stored water. Streamflow regulation has been shown to be effective in reducing the impacts of acid mine drainage during low flow periods and could be effective in the Sand Coulee drainage.

TABLE 23. POTENTIAL ABATEMENT OR CORRECTIVE TECHNIQUES FOR ACID MINE DRAINAGE PROBLEMS IN THE SAND COULEE AND BELT AREAS

	Effluent Control			Mine Manipulation			Infiltration Control	
Mine Number	Streamflow Regulation	Evaporation Ponds	Neutralization	Dam and Flooding	Seal using Mine Backfill	Hydraulic Seal	Overburden Water Removal Using Wells	Vegetative Evapotranspiration
SCM 2	U	0	P	0	0	V	P	V
SCM 3	U	P	P	0	0	V	P	V
SCM 4	U	0	P	0	0	V	P	V
SCM 5	U	P	P	F	0	V	P	P
SCM 6	U	P	P	0	0	V	P	P
SCM 7	U	P	P	0	0	V	P	P
SCM 8	U	P	P	0	0	V	P	P
SCM 9	U	P	P	0	0	V	P	P
SCM 11	U	P	P	0	0	V	P	P
SCM 15	U	P	P	0	0	V	P	P
BM 1	U	0	P	0	0	V	P	V
BM 2	U	P	P	0	0	V	P	V
BM 3	U	P	P	0	0	V	P	P

Applicability

F = Fair

P = Poor

0 = No Potential

U = Undetermined

V = Variable - insufficient technical data to determine potential cost effectiveness

In the Belt drainage there has been no consideration of dam sites and there is little potential that major reservoirs would be considered in the vicinity of the abandoned coal mines.

Evaporation Ponds

Large evaporation ponds are commonly used for disposal of waste waters. Acid mine drainage would need to be collected and conveyed to a pond, or series of ponds, and the water then would be lost to the atmosphere through evaporation. No discharges to surface or groundwater would occur. Bottoms of the ponds would need to be lined where the impoundment bottom is permeable. The system must be designed to have capacity to handle evaporation of precipitation entering the pond and the inflowing mine wastewater. The ponds would periodically need to be cleaned and solids removed and transported to a suitable burial site.

Based on evaporation data for Montana (SCS, 1974) a total net evaporation of approximately 27 inches per year is estimated for the Belt-Sand Coulee area. There are several important considerations in the use of the evaporation technique. In Montana, evaporation is restricted to the warm portion of the year and it commonly is assumed that from November through April no evaporation occurs. This requires storage of all the water from the mine during this period and storage of the precipitation that occurs during this six month period. Each gallon of water flowing from an abandoned mine for a six month period requires approximately 260,000 gallons of storage. This is a large storage requirement and requires a large relatively flat area for pond placement. The high construction cost and requirement for a relatively flat area restricts this technique to mines with small outflows.

Cost of constructing an impounding structure, including materials, compacting and grading, is estimated to be approximately $1.50 to $2.50 per cubic yard. Lining costs depends on the type of material used and

the area covered. Liners probably will range in cost from \$0.15 to \$0.35 per square foot. Riprap and vegetative cover for slope protection also must be considered in the impoundment facility. Assuming a continuous mine discharge of 5 gpm, an evaporation pond system would require about 4 acres of land and would cost from \$30,000 to \$100,000. Cost is very dependent upon the need for an impervious liner. This does not include the cost of land purchase, piping, easements, legal and engineering services. Evaporation ponds also require annual maintenance that would include inspection and repair of the dikes, piping system, vegetation control and periodic removal of evaporated solids.

Evaporation ponds will work for small mine flows but initial costs are high, land requirements are large and seepage control would be costly.

Neutralization

Neutralization of acid mine drainage by lime and limestone is probably the most widely used technique for water treatment of acid mine waters. There have been hundreds of reports on neutralization of acid mine drainage from coal seams. Neutralization has been discussed by the EPA (1973, 1975), the Appalachian Regional Commission (1974), and neutralization procedures were examined by McArthur (1970) in his study of treatment of waters in the Sand Coulee Creek drainage.

Many substances have been considered for neutralization including lime, limestone, caustic soda, soda ash, dolomite, and fly ash. It has been found that for most applications lime and limestone are by far the most cost effective materials.

The chemistry of lime (CaO) and hydrated lime ($Ca(OH)_2$) neutralization of acid waters has been described by numerous investigators including the Applachian Regional Commission (1974). The reactions of lime with AMD have been determined. Products of the reaction are salts and water. The reaction neutralizes sulfuric acid and increases

Groundwater

There have been no detailed studies of groundwater resources in the Belt area. Fisher (1909) described geology and water resources of a large area in south central Montana including the Belt area. The occurrence, movement, abundance and quality of groundwater is closely related to geology of the area. Formations of particular importance are the Kootenai and Morrison Formations and unconsolidated alluvium adjacent to and underlying Belt Creek.

The Kootenai Formation is present at the ground surface in much of the drainage. This formation is widely used in this part of Montana as a source of stock and domestic water. The Kootenai is fractured and jointed and has a permeable basal sandstone. This formation probably will yield water to wells in the Belt area.

The Morrison Formation is beneath the Kootenai. The upper part of the Morrison consists of impervious shale layers that limit downward movement of groundwater. The lower Morrison contains some sandstone layers and lenses that probably will yield water to wells.

Discharge from the abandoned coal mines comes, at least in part, from the coal seam. It is probably that the coal is in hydraulic contact with the Kootenai Formation and groundwater is moving vertically from the basal Kootenai downward into the coal then laterally into the abandoned mine workings.

Unconsolidated alluvium along Belt Creek contains abundant groundwater. The community of Belt obtains its water supply from a 28 foot deep well in alluvium that yields 700 gpm. Upstream from Belt, some residents obtain water for domestic irrigation purposes from wells in alluvium.

Recharge of groundwater is from precipitation and, in the alluvium, from seepage from Belt Creek. Groundwater discharge is to wells, springs and discharging mines.

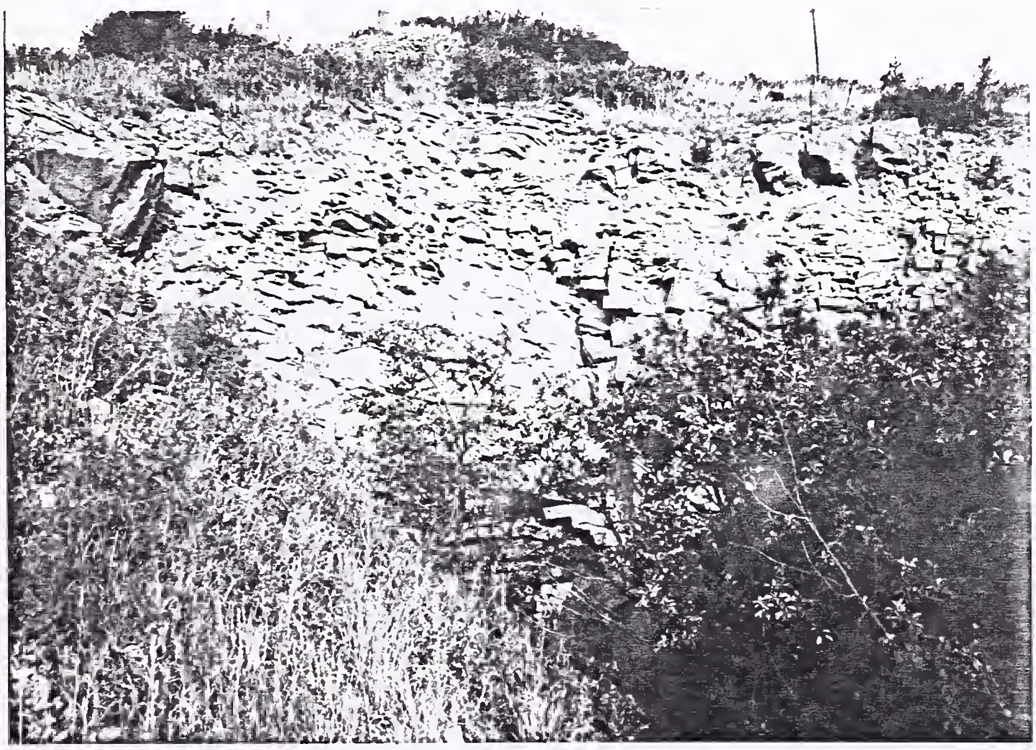
DESCRIPTION OF MINES

Each discharging mine in the Belt area was examined to determine its characteristics and condition. Table 19 summarizes the mine conditions and the locations.

Mine BM 1

Mine BM 1 is located just southeast of the community of Belt on a steep sidehill near the community water storage tank (Figure 7). The mine portal has collapsed and water drains into a pipeline and surfaces some distance downhill from the adit. Water from the adit cascades over waste piles down a steep slope and enters a small stream that eventually flows to Belt Creek. The stream channel is heavily encrusted with iron precipitate.

Flow from BM 1 has ranged from 80 to 166 gpm (Table 16) and the effects of heavy precipitation in May 1981 had little affect on the mine discharge.



BM 1 - Mine Portal

pH and alkalinity. The reactions are:

$$CaO + H_2O \longrightarrow Ca(OH)_2$$

$$Ca(OH)_2 + H_2SO_4 \longrightarrow CaSO_4 + 2H_2O$$

$$3\ Ca(OH)_2 + Al_2(SO_4)_3 \longrightarrow 3CaSO_4 + 2\ Al(OH)_3$$

$$Ca(OH)_2 + FeSO_4 \longrightarrow Fe(OH)_2 + CaSO_4$$

$$3\ Ca(OH)_2 + Fe_2(SO_4)_3 \longrightarrow 2\ Fe(OH)_3 + 3\ CaSO_4$$

In addition to increasing pH and decreasing acidity, lime treatment removes many metals including aluminum, iron, and manganese. Calcium sulfate increases water hardness until its maximum solubility is reached, then it precipitates.

Limestone neutralization is accomplished according to the following equations:

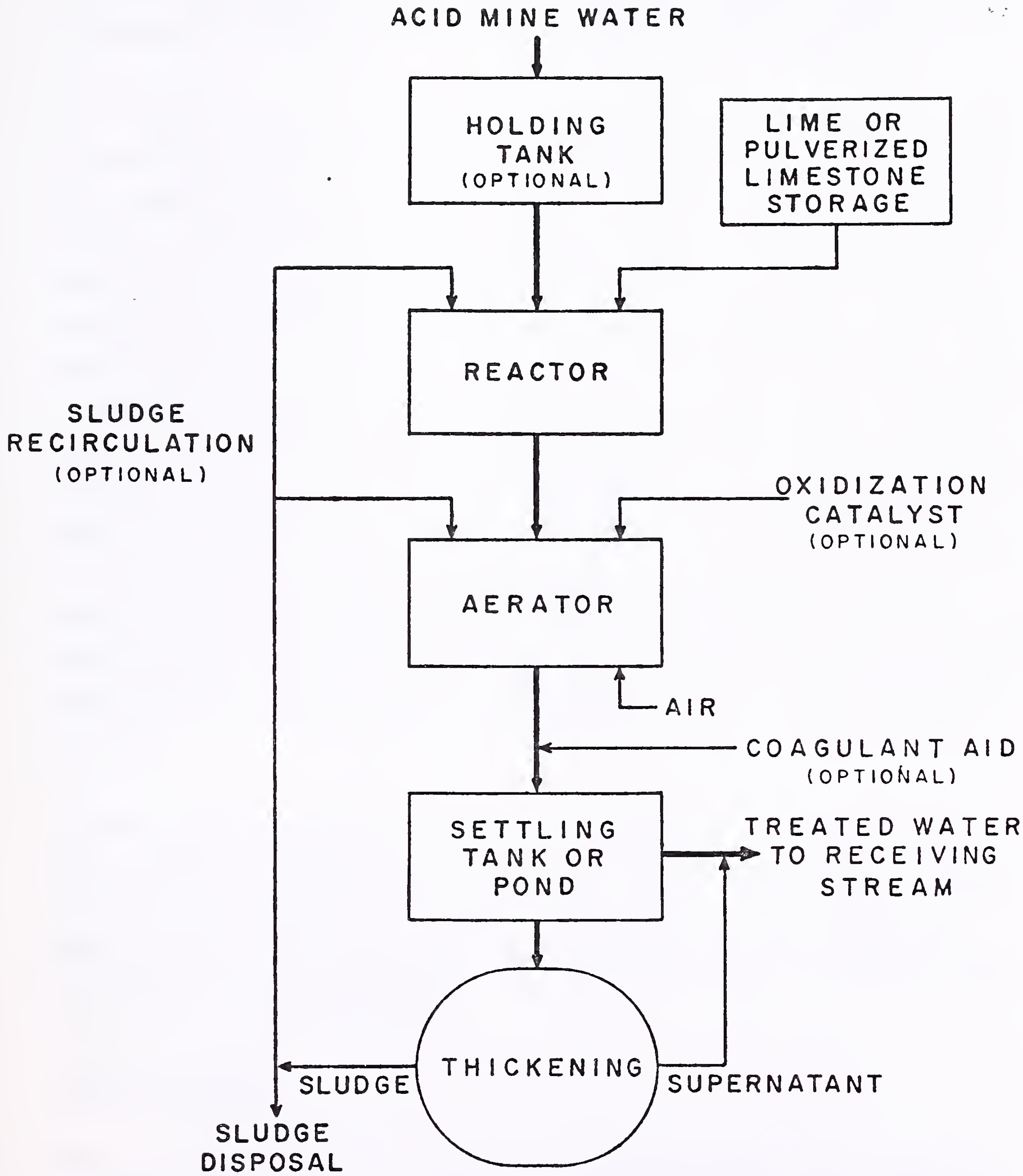
$$CaCO_3 + H_2O \longrightarrow CaO + H_2CO_3$$

$$CaO + 2H^+ \longrightarrow Ca^{++} + H_2O$$

A conventional lime or limestone neutralization process consists of a reactor aerator, settling tank and sludge thickener (Figure 11). The neutralized water is returned to the stream. Another application is the use of a rotary drum filled with limestone. Stream water rotates the drum and the water is partially neutralized during flow through the drum (Pearson and McDonnell, 1978).

A neutralization facility can be established at the mine, along a stream, or at a central location for collection of AMD. Any facility is designed for a specific flow range and flows less or greater than the design flow are less efficiently handled.

A lime or limestone treatment facility is a chemical process plant and must be properly designed, constructed and operated to adequately



SCHEMATIC DIAGRAM

FIGURE 11. CONVENTIONAL LIME OR LIMESTONE NEUTRALIZATION PROCESS (after McArthur, 1970).

neutralize acid water. The plants must function in the Montana winter environment and under a variety of acid loads and flows. To provide a continuous neutralization, the plant must be operated continuously. If neutralization stops, the effluent would quickly become acid.

All mine effluent in the Sand Coulee and Belt Creek drainages can be successfully neutralized using lime or limestone. However, the cost and long-range success of neutralization must be considered. McArthur (1970) examined the cost of treating acid waters in the Sand Coulee drainage. He estimated the operating cost for a 750 gpm conventional limestone neutralization facility to be about $223,000 per year. This did not include costs to convey acid water to a central treatment point. A revolving drum facility was estimated by McArthur (1970) to have a capital cost of $11,140 and an annual operating cost of $7,240 per year to treat 40 gpm. Other costs not considered are land easements and acquisition and legal and engineering fees. It can safely be assumed that present day capital costs for these facilities would be much greater than estimated by McArthur. Lime neutralization costs also have been estimated by the EPA (1973). Plant cost is estimated to be about $245,000 for a 500 gpm plant and operating costs are about $450,000 per year.

Limestone or lime neutralization does not provide a permanent solution to AMD unless operated continuously. There seem to be no potential in-stream benefits in Sand Coulee Creek or in Belt Creek that would justify the large capital and operation costs of neutralization facilities in these drainages.

Dam and Flooding

The use of small dams to inundate and flood abandoned mines theoretically would reduce oxidation of pyrite in the mines and improve effluent quality. Based on analysis by the EPA (1973) this technique has not been domonstrated to determine its feasibility and effectiveness but is theoretically sound and could have potential application to AMD problems.

Mine SCM 5, located in a small side tributary of Sand Coulee near the community of Sand Coulee, potentially could be flooded by placement of a small dam in this drainage. This coulee is isolated, narrow and has exposed bedrock on the coulee sides. McArthur (1970) also suggested flooding as an abatement technique for this dam. He concluded that flooding may be feasible and the total annual cost of a mine flooding dam would be about $1800. (This annual cost would now be much higher.)

Other mines in the Sand Coulee Creek drainage also could be flooded by placement of large dams including those upstream from Sand Coulee and those in Cottonwood Creek. The use of a large dam for flooding probably would not be a cost effective technique. Multi-purpose dams in the drainage possibly could be considered for flood control and recreation and, mine flooding would be an additional potential benefit. There is no opportunity for flooding of discharging mines in the Belt area.

Mine Sealing

There have been a number of demonstrations of the effectiveness of mine sealing and it has emerged as a suitable technique and, more importantly, a permanent technique for controlling acid drainage. There are a large number of methods for plugging mines as described by the EPA (1973, 1975) and the Appalachian Regional Commission (1974). Mine sealing techniques generally are divided into air seals which involve sealing of all openings into the mine through which air may enter and hydraulic seals which essentially impound water and flood the mine.

Air seals have had poor success. It has been found that air continues to enter the mine workings in spite of the seals. In the fractured rocks associated with mines in the Sand Coulee and Belt area it is doubtful that air sealing would work. The rapid movement of water into these mines suggests that air also could move through the fractures

into the mine. The EPA (1975) concluded that air sealing can be of value under some circumstances to improve the quality of acid mine water; however, in most cases air sealing is not effective.

Hydraulic seals are used when it is desired to eliminate the discharge of water from a mine opening. This type of seal impounds water within the mine workings and reduces the rate of acid water production. The seal, along with the outcrop barrier, must withstand the maximum hydraulic head generated by the water if the seal is to be successful. A number of types of hydraulic seals have been developed and tested including double and single bulkhead, concrete, gel, clay and grout bag seals.

Double bulkhead seals are constructed by placing and grouting of two aggregate bulkheads at a predetermined spacing within the mine opening - usually in a drift or adit. The space between bulkheads is then filled with cement. Simultaneously, the outcrop is usually curtain grouted to improve the structural properties of the adjacent area. Both bulkheads and cement are placed through boreholes, thereby allowing sealing of caved openings.

Single bulkhead masonry seals are constructed using a keystone arch design which is notches into the roof, ribs and floor. It is usually made from precast block or brick. Single bulkhead seals also can be constructed by notching the roof, ribs, and floor and pouring a solid concrete seal over reinforcing rods. The seal usually has a drainpipe with a valve and a gas test pipe penetrating the slab.

Another type of single bulkhead seal can be constructed by injecting a gel material and aggregates into a borehole at the location of the seal. The gel material sets up quickly, thereby eliminating the need for pre-constructed bulkheads to contain the material.

Gunite bulkhead seals can be constructed by tapered notching of the roof, ribs, and floor. At the end of the notch, a wooden barrier is constructed. The area is then filled with gunite, a pneumatically placed low slump concrete, in nearly vertical layers until the opening is filled. This type of seal has not been field tested to date.

Clay seals are constructed by placing and compacting clay in the opening to a specified distance, and backfilling over the seal to secure it and prevent erosion. The area must be cleared of all material that may be deleterious to the seal, and the clay used must meet rigid technical standards.

The grout bag seal is an experimental seal designed for use in accessible drifts. It is constructed by stacking nylon bags within the opening to be sealed and then inflating them with a fast setting concrete.

Selection of the appropriate seal depends on a large number of variables including characteristics of the underground mine opening, strength and permeability of the wall floor and roof rock, installation, operation and maintenance costs and hydrostatic pressure. The best seal technique can be selected only after careful hydrological, geotechnical and geological evaluation of the specific mine. None of the mines near Belt or in the Sand Coulee drainage have had adequate technical investigations to allow selection or design of a hydraulic mine seal.

Hydraulic seals are subject to numerous constraints and problems including leakage through and around the seals, failure of the seal or failure of walls or barriers in the mine due to increased water pressure. Areas considered too weak to withstand flooding and water pressure may require reinforcement using measures such as grouting.

Similarly, fractured rock and coal may require fan grouting or injection of sealants to reduce leakage. Specific considerations for mine seals in the Sand Coulee and Belt areas are the presence of fractured rock at the mine portals and unstable wall and roof materials that, in many mines, have collapsed.

Typical bulkhead seals are shown in Figures 12 and 13. These illustrate the basic concept of hydraulic seals. A wide variety of designs can be used to best handle a specific mine problem. Excessive increases in pressure behind seals can be prevented by boreholes that will allow discharge at a specific mine water pressure. Seals also can be designed to allow normal mine drainage if undesired adverse effects are caused by the sealing. The AMD drainage situation then would return to the pre-sealing condition.

Interviews with local residents discerned that during mining "sulphur balls" (pyrite nodules) were discarded and left lying on the mine floors. It is possible that not all of the mine workings are presently flooded. If a seal were constructed and water levels in the mines raised, increased production of AMD may occur for some period of time after flooding.

Seal Using Mine Backfill

There has been considerable interest in removal of coal mine wastes in the Sand Coulee and Belt areas and placement of these wastes into abandoned mines. Such wastes alone would not be a suitable mine seal. These wastes potentially could be incorporated into or combined with other materials such as cement to provide the overall performance needed in a hydraulic seal. Mine wastes also could be placed into abandoned mines behind single or double bulkhead hydraulic seals. Generally, however, backfilled mine wastes are not of significant value for use in hydraulic seals.

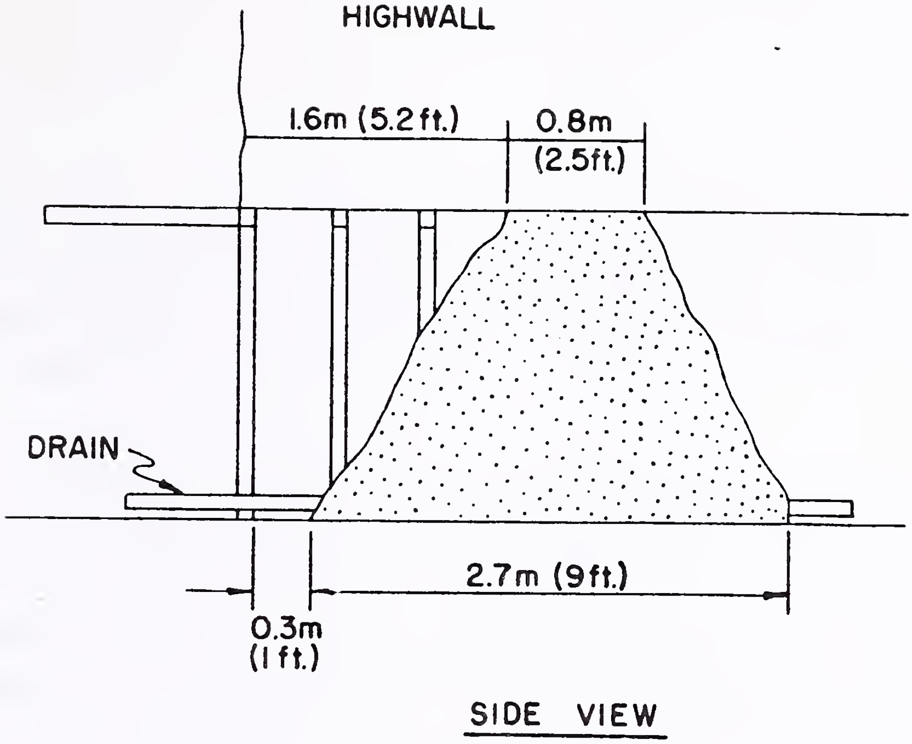


Figure 12. Typical Single Bulkhead Seal (after EPA, 1975).

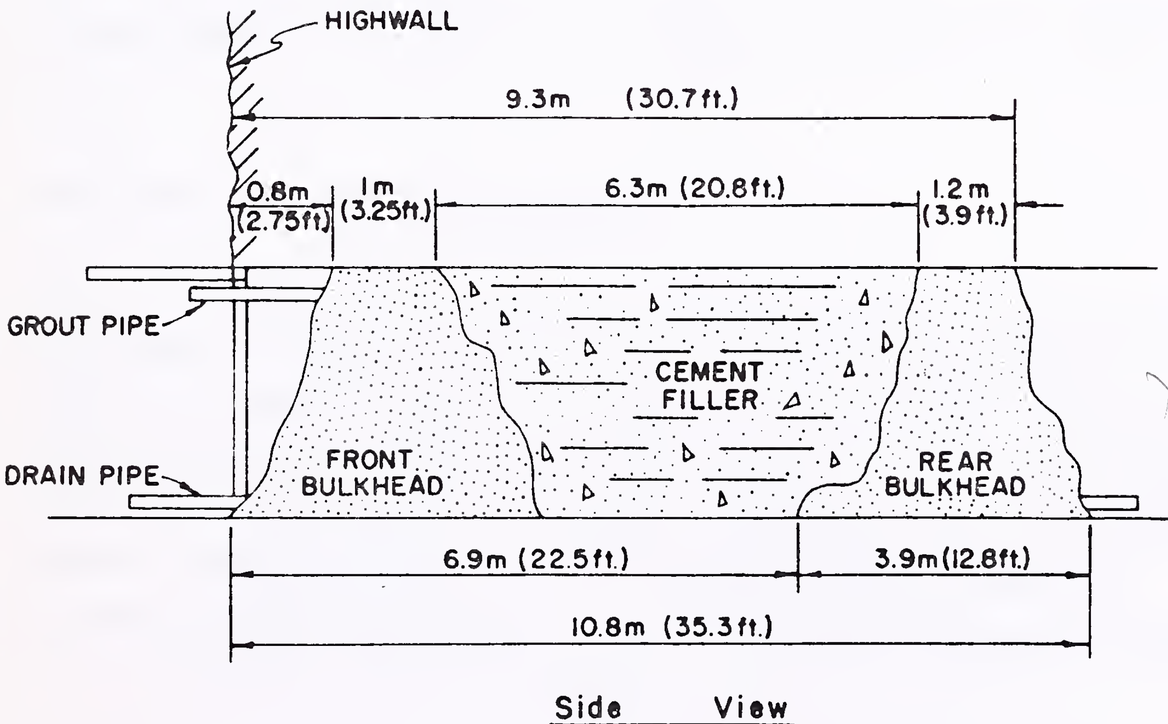


Figure 13. Typical Double Bulkhead Seal (after EPA, 1975).

Cost of mine seals obviously depends on the individual mine requirements and the sealing technique selected. Costs of some typical hydraulic seals will provide some insight into potential costs for the Sand Coulee and Belt areas.

Cost of grouted double bulkhead seals at abandoned mines in Pennsylvania were estimated to average $21,000 (1974 costs) including all contractor and material costs and reinforced concrete seals were $15,000 to $20,000 (Appalachian Regional Commission, 1974). Grouting to reduce the possibility of seepage around seals is estimated to cost $25 to $80 per linear foot of grout curtain (EPA, 1973). Single bulkhead seals ranged in cost from $2100 to $6000 each and clay seals ranged from $1200 to $4000 per seal (EPA, 1973). If suitable and, if successful, hydraulic seals offer the potential for long-term control of acid drainage at a reasonable cost.

Much mine-specific work must be completed to determine the potential for application of hydraulic seals to mines in the Belt and Sand Coulee areas.

<u>Overburden Water Removal Using Wells</u>

Wells are widely used for removing water from aquifers intercepted by underground or open pit mines. The objective of dewatering is to remove the groundwater before it enters the mine workings. Assuming most groundwater entering underground workings in the Belt and Sand Coulee areas is derived from permeable sandstones in the overlying Kootenai Formation, then a series of dewatering wells above and peripheral to the underground mine workings should effectively reduce the flow of water into the workings.

Two techniques can be used to remove water from the Kootenai Formation. The first would be to drill wells into the basal sand or conglomerate in the Kootenai Formation and pump groundwater to the ground surface

and remove the groundwater from the area to a nearby drainage. Another option is to construct "connector wells". These wells would extend through the Kootenai Formation, through the coal seam in the Morrison Formation and into an underlying aquifer (Figure 14). The objective of these connector wells would be to allow groundwater to enter the well in the Kootenai Formation, move downward within the well to the underlying aquifer and then enter the underlying aquifer. Connector wells essentially act as a short circuit to allow groundwater to move from the Kootenai Formation to a lower aquifer, thereby eliminating water inflow into the abandoned mine workings. Both of these techniques require knowledge of the locations of the underground mines, an understanding of aquifer hydraulics, and in the case of connector wells, an understanding of aquifers underlying the coal seam.

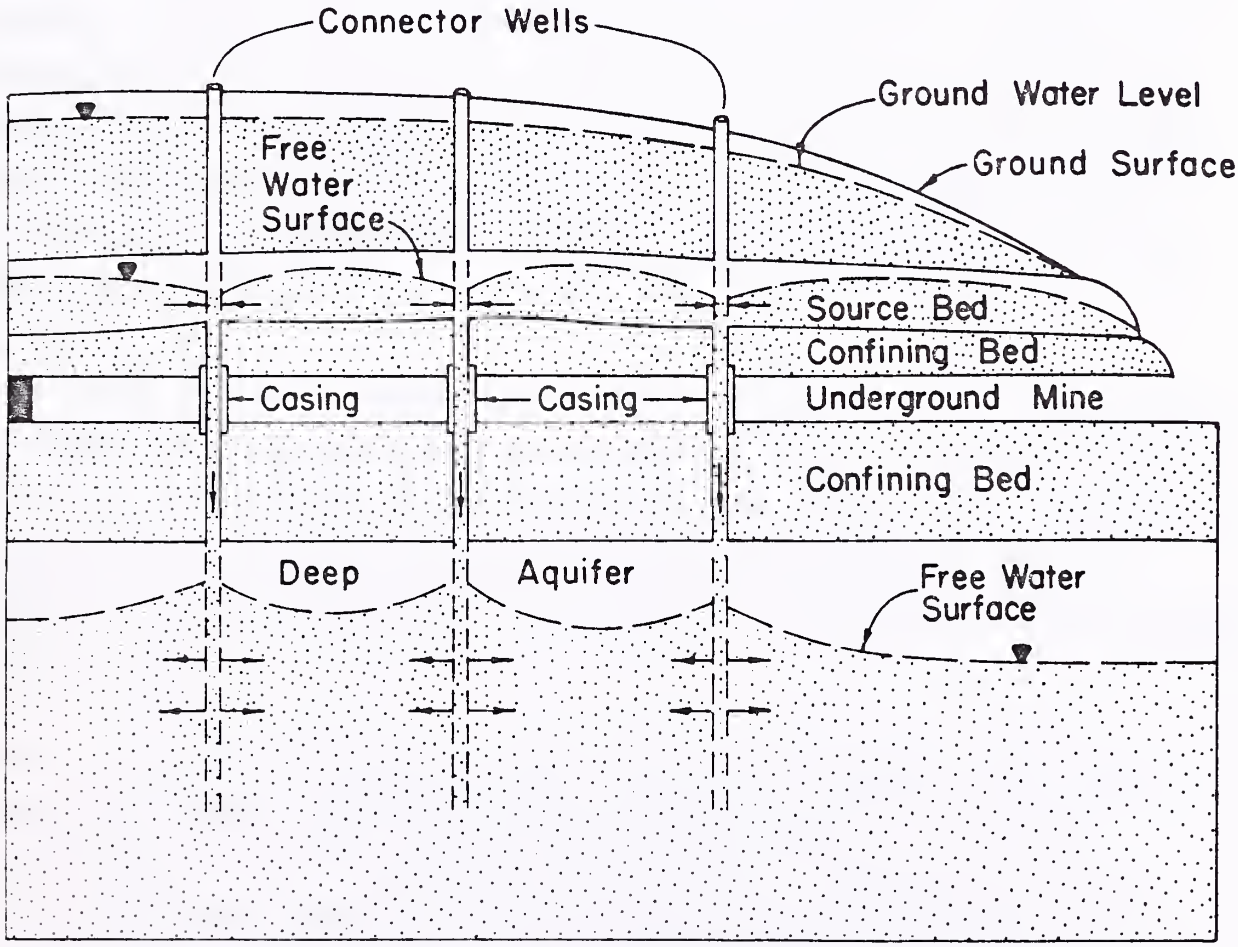


Figure 13. Cross Section of a Mine Utilizing Collector Well System (from EPA, 1975)

Wells utilized to pump groundwater to the land surface also pose a number of problems, including the effort and cost required to construct the wells, connection of the wells through a piping system, supply of power for the pumps, and disposal of pumped water. Another problem with this technique is that dewatering of the Kootenai Formation also may impact springs and wells present in the Kootenai Formation near the dewatering area. An additional potential problem with this technique is the possibility that water in the coal mines may migrate in laterally from the coal seams, thereby requiring dewatering of the coal peripheral to the underground mine workings. This technique also requires detailed knowledge of the location of underground workings.

The use of connector wells would allow groundwater to flow by gravity from the Kootenai Formation downward into an underlying aquifer. This, however, assumes that hydraulic heads in the underlying aquifer are lower than in the Kootenai Formation (if the heads are not lower the flow would not be downward) and further assumes the underlying formation has adequate hydraulic capacity to accept and transport water from the Kootenai Formation. Figure 13 shows the operation of a connector well system.

Both these dewatering techniques require construction of a large number of wells and periodic inspection and maintenance of these wells would be necessary to insure their continuing proper operation. If water is pumped from the wells, a complex and expensive piping and pumping system would be required and there would be a continuing cost for groundwater removal.

The technique of groundwater removal to prevent movement into underground coal mines has not been used in the western U. S. and the applicability of this technique is uncertain. A computer model was used by Schubert (1978) to estimate the effectiveness of dewatering wells and removal of water from underground workings overlain by a permeable sandstone. Conclusions of this computer simulation were

that a significant reduction in inflow rate into the mine would not be feasible under the geologic, hydrologic, and mining conditions identified in that study. There have been no on-the-ground demonstrations of this technique.

Although this dewatering technique is technically difficult and expensive, it does represent a potential method for long-term reduction of acid drainage from the abandoned mines. Effectiveness of the technique, however, needs to be demonstrated. Considerable hydraulic testing of the Kootenai Formation is needed and an evaluation is needed of aquifers underlying the Kootenai that could be utilized for disposal of groundwater removed from the Kootenai Formation.

Pumpage of water to the ground surface and subsequent removal by pipelines probably is technically feasible, however, cost of construction of a dewatering system; an inadequate knowledge of the location of underground mine workings and the potential for interference with water in existing wells and springs suggests the overall applicability of this technique to AMD problems in the Sand Coulee and Belt areas would be limited. Cost of groundwater dewatering is unknown and costs cannot be determined until hydraulic tests are conducted on aquifers in the drainage.

Vegetative Evapotranspiration

As described in the Agricultural Practices technical report, the saline seep phenomena in Montana is considered to be caused by accumulation of excess moisture in the soils and vertical downward movement of this moisture beyond the root zone to the water table. Cause of increased infiltration is considered to be allowing large blocks of land to lie fallow (plowed but unplanted). The basic assumption is that excess moisture associated with saline seep is locally derived and would not have reached the regional groundwater flow system if plants had been available for evapotranspiration of water at the ground surface and from the shallow soil.

There has been considerable research in Montana on saline seep and it has been found that an effective abatement technique is planting of high water use crops such as alfalfa or continuous cropping. This vegetative control is effective in reducing infiltration and lowering groundwater tables.

A potential application of this technique to AMD would involve determination of the drainage area contributing to the underground mines and planting of high water use crops or to continuous cropping in the infiltration area. This technique has never been attempted for abatement of acid drainage, however, its success in saline seep would suggest it could be effective as a control technique.

This technique, however, has some serious drawbacks, including requiring changes in cropping patterns, sustaining the crops during drought periods, and location of areas of infiltration contributing to underground mine workings. These are all formidable problems; however, the technique potentially could significantly decrease infiltration and also could be an economic farming method. There is insufficient information in the drainage to determine the feasibility of this technique. Mine sites that have significant farming activity in their potential areas of infiltration are SCM 2, SCM 3, SCM 4, BM 1 and BM 2. If vegetative evapotranspiration is to be attempted, these mine areas should be considered. It is interesting to note that mines SM 2 and SM 4 contribute about 80 percent of the entire pollution load in the Sand Coulee drainage and BM 1 contributes about 80 percent of the pollutant load in the Belt area.

Application of this technique would require obtaining information on locations and extent of old workings, determination of the infiltration area overlying mine workings and potential cropping patterns that could be changed to increase evapotranspiration losses. This information would allow determination of potential for success for new cropping patterns and the potential for these new cropping patterns to utilize water that normally would have infiltrated beneath the soil zone into

the groundwater system. This program also would require an intensive monitoring system consisting of measurements of soil moisture, precipitation, mine effluent flow and quality. This information would be needed to determine effectiveness of changes in cropping patterns on infiltration and AMD.

RECOMMENDED FUTURE PROGRAMS

The Sand Coulee and Belt areas are the most significant instances of acid mine drainage from abandoned coal mines in Montana. These areas also are the present target of considerable coal exploration and it is possible that coal mining could again occur on a major scale in these areas. It is important to understand and, if possible, control existing AMD problems in Sand Coulee and Belt and to carefully plan future mining to avoid adverse water resource impacts.

Existing AMD Problems

It is probable that there are no cost effective solutions to existing AMD problems in the Sand Coulee and Belt areas. Results of extensive investigation of existing AMD problems in these areas show there are no economical alternatives to restore streams to their former unpolluted condition. Past mining practices in the Sand Coulee and Belt areas obviously have created significant water resource problems that will persist for many decades or possibly indefinitely into the future.

The present availability of federal and state funding to correct existing AMD problems is of major importance. These funds should be used to test the feasibility of AMD control at abandoned coal mines. There have been no tests of AMD control techniques at coal mines in Montana and nearly all the acid drainage abatement and control technology has been developed and control feasibilities demonstrated at abandoned mines in the eastern United States. Of particular importance is to demonstrate the feasibility of long-term solutions to the existing AMD problems.

At-source control measures considered to have potential application to abating or eliminating AMD in the Sand Coulee and Belt areas are hydraulic mine seals, vegetative evapotranspiration and overburden water removal using wells. These control methods, once implemented,

require relatively little maintenance and operating costs are low. Mine hydraulic seals, in particular, have been used in many mines and, in some cases, have been found to be a low-cost long-term solution to AMD. Hydraulic seals deserve detailed evaluation for application to mine specific problems in the Sand Coulee and Belt areas. A field demonstration of a hydraulic seal at a mine site would be of major importance in development of AMD control in Montana. The use of connector wells and vegetative evapotranspiration are completely untried techniques and are less attractive as potential solutions to AMD. These techniques can, in theory, work and should be further evaluated for feasibility demonstrations at specific mine sites.

Effluent techniques involve high capital costs and are expensive to operate and maintain. The long-term use of treatment techniques for solving AMD problems seems inappropriate in that long-range funding is uncertain and continued operation and maintenance of treatment facilities cannot be assured.

Future AMD Problems

Mining of high sulphur coal from the Great Falls-Lewistown coal field could occur in the next ten years. Presently, coal exploration drilling is being conducted at several sites and the Montana Power Company has announced that Great Falls will be the site of a large coal-fired steam electric generation plant.

Existing AMD problems in the Sand Coulee and Belt areas clearly shows what can happen if mining is not conducted to minimize environmental impacts to water resources. Present mining regulations (see Regulatory Framework section) require careful mine planning, construction, operation and reclamation to minimize water resources impacts.

A technical demonstration of the feasibility of hydraulic mine seals would be of significant value in design of appropriate post-mining water resources protection measures. Similarly, detailed technical evaluations of other at-source control techniques and effluent treatment methods for specific mine sites should be made to determine if a field demonstration of feasibility should be conducted. The hydrology and AMD control efforts conducted to date provides an excellent background for implementation of mine specific AMD solutions in the Sand Coulee and Belt areas and also provide a good framework for planning future mines in this coal field.

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Bill Zitz, Great Falls Office of the Soil Conservation Service (SCS). re: Discharging mines in the Belt area, 7-16-80.

Neal Walker, Harlowton Office of the SCS. re: RAMP program administration in Belt area, 7-16-80.

David Olson, National Weather Service, Great Falls. re: Climatological data for Sand Coulee-Belt area, 7-16-80.

Jewel Browning, banker, resident of Belt. re: Location of discharging mines and tailings, 7-16-80.

John G. Mittal, retired miner, resident of Sand Coulee. re: Mining history and various aspects of local water resources, 12-8-80.

Archie McDonnell, Penn State University. re: Design criteria for limestone barriers and biological oxidation to remove iron, 1-7-81.

Dr. Richard Parizek, Penn State University. re: Mine dewatering techniques, 1-8-81.

Joe Donovan, Montana Bureau of Mines. re: Mine discharge measurement, 1-20-81.

Dr. Harold Lovell, Penn State University. re: Short course on treatment of AMD at Penn State, 1-26-81.

Bill Farmer, Virginia Polytechnic Institute. re: Work in AMD, 1-26-81.

Richard Smith, West Virginia University. re: Work in AMD, 1-26-81.

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Gary Ingman, Water Quality Bureau, Helena. re: Existing water quality information, 2-2-81.

Ed Juran, Butte SCS. re: RAMP administration, 2-4-81.

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EXHIBIT 1.

Plan Map of the Sand Coulee Drainage

EXHIBIT 2.

Surficial Geological Map of
the Kootenai Formation

EXHIBIT 3.

Groundwater Potentiometric Map of the Kootenai Formation